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TOOL STEEL

FOR THE NON-METALLURGIST

CRUCIBLE® STEEL COMPANY OF AMERICA

Four Gateway, P.O. Box 88, Pittsburgh, Pa. 15230

188
1.00

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TYPICAL ANALYSES OF GRADES

"Tool Steel for the Non-Metallurgist"

AISI	*Grade*	*C*	*Mn*	*Si*	*Cr*	*V*	*W*	*Mo*	*Co*
	Water Hardening								
W1	Sanderson Extra	1.05	.25	.20	—	—	—	—	—
W2	Alva Extra	.95	.25	.20	—	.20	—	—	—
W4	Sanderson Special	1.10	.30	.50	.25	—	—	—	—
	Oil Hardening								
O1	Ketos	.90	1.35	.35	.50	—	.50	—	—
	Shock Resisting								
S1	Atha Pneu	.55	.25	.25	1.25	.20	2.75	—	—
S5	LaBelle Silicon #2	.60	.85	1.85	.25	.20	—	.30	—
L2	Halvan	.50	.80	.30	1.00	.20	—	—	—
	Air Hardening								
A2	Airkool-S	1.00	.70	.30	5.25	.30	—	1.15	—
D2	Airdi 150-S	1.55	.35	.45	11.50	.90	—	.80	—
D4	HYCC	2.25	.35	.50	11.50	.20	—	.80	—
	Hot Work								
H11	Halcomb 218	.40	.40	1.05	5.00	.50	—	1.35	—
H12	Chro-Mow	.35	.35	1.05	5.00	.35	1.25	1.35	—
H21	Peerless A	.30	.30	.30	3.35	.25	9.00	—	—
H43	Rex VM PX Temper	.50	.30	.30	4.00	1.95	—	8.00	—
	High Speed								
M2	Rex M2S	.85	.30	.30	4.15	1.95	6.40	5.00	—
M1	Rex TMO	.85	.30	.30	3.75	1.15	1.55	8.70	—
M10	Rex VM	.90	.30	.30	4.00	1.95	—	8.00	—
T1	Rex AA	.75	.30	.30	4.00	1.15	18.00	—	—
T4	Rex AAA	.75	.30	.30	4.00	1.15	18.00	.75	5.00
T8	Rex 95	.80	.30	.30	4.00	2.00	14.00	.75	5.25
—	Rex 49	1.10	.45	.30	4.25	2.00	6.75	3.75	5.00
T9	Rex 4V	1.25	.30	.30	4.00	4.00	18.50	.75	—
M3	Rex M3S-1	1.05	.30	.30	4.00	2.40	6.25	6.25	—
M3	Rex M3S-2	1.20	.30	.30	4.00	3.00	6.25	6.25	—

PREFACE

It is the aim of this booklet to present a practical understanding of Tool Steels without being overly technical. Because of this aim the presentation has been purposely confined to direct, familiar phrases.

Below are listed the Crucible Tool Steels discussed in this booklet:

Water Hardening:

Alva® Extra—Shallow Hardening
Sanderson Extra—Medium Hardening
Sanderson Special—Deep Hardening

Oil Hardening:

Ketos®

Shock Resisting:

LaBelle® Silicon #2
Halvan®
Atha Pneu

Air Hardening:

Airkool
Airdi® 150
HYCC®

Hot Work:

Halcomb 218
Chro-Mow®
Peerless A
Rex® VM, PX Temper

High Speed:

Rex M2®S—Rex TMO®—Rex VM®—Rex® AA
Rex AAA—Rex 95—Rex 49
Rex 4V—Rex M3S-1—Rex M3S-2

TOOL STEEL FOR THE NON-METALLURGIST

There has existed for many years an air of mystery surrounding the selection, heat treatment, and use of tool steels. Started by the secretiveness of the early makers, it has been fostered somewhat by the never ending introduction of new grades.

In working with the diverse and special requirements of tool steels, Metallurgists understand the existence of so many different analyses. This situation is not unlike that of the Chemist, who appreciates the infinite number of chemical compositions possible and the practical value of innumerable compounds.

Many shop men and engineers, whose technical training in metal working has been devoted to other phases, on occasion, rub elbows with tool steels. For them, this simple approach to the understanding of tool steels is presented. Familiarity with the six basic types of tool steels will help to successfully handle the numerous grades which are modifications within these types.

The six basic types to be discussed are listed on page 5 with Crucible grades grouped under each for ease of discussion. These grades are representative of the many which are required to serve both regular and special applications. The order of presentation in this booklet will be to start with the simplest type (least amount of alloys), the Water Hardening Carbon Tool Steels. Progressively, those types with increasing amounts of alloying elements will be discussed.

After each grade in the listing of Water Hardening Steels, a descriptive phrase has been added to pin point the outstanding value of each steel within the group. However, this phrase cannot be used to compare a steel of this group with that of another. For example, describing Sanderson Special as "Deep Hardening" does not mean that it hardens deeper than Ketos or Rex M2. It does have meaning within the first group indicating that Sanderson Special will harden deeper than any of the other Water Hardening groups.

Before considering the specific grades, two thoughts, which should always be associated with tool steel, are

worthy of mention. First, the term tool steel denotes a special quality. It is generally understood that all tool steels are electric furnace melted. Careful processing and conditioning are practiced during the many mill operations from ingot to finish product. Extreme care is exercised in each heating operation. Rigid physical and chemical standards are maintained to uphold this distinct level of quality.

Secondly, actual job experience will dictate the final selection of a tool steel. This not only encompasses the nature of the steel itself, but also includes other factors. Some of these are available heat treating facilities, the behavior of the steel while being shaped into a tool, and whether long or short production runs are planned.

Each grade has outstanding properties which will best serve the requirements of an individual job. The manner in which the groups are classified as well as distinction among grades within each group signifies the variety of traits in tool steels. There is no one tool steel which will be superior in all respects.

Analysis of the job will at first result in the selection of one of the six basic types. Further examination will indicate the need for specific qualities in the tool steel. It then follows that a particular grade which has the best balance of properties to match the job will be the final choice.

WATER HARDENING CARBON TOOL STEELS

	Analyses				
Grade	*C*	*Mn*	*Si*	*Cr*	*V*
Alva Extra	.95	.25	.20	—	.20
Sanderson Extra	1.05	.25	.20	—	—
Sanderson Special	1.10	.30	.50	.25	—

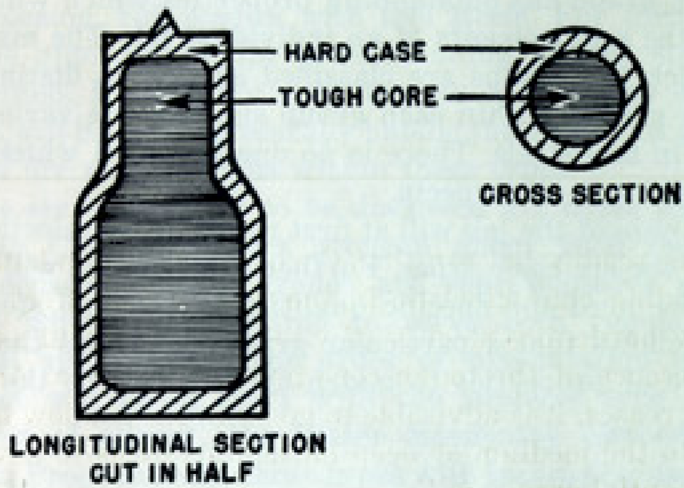
Carbon Tool Steels have carbon as the principal control element generally in the range of .85/1.15%. When hardened, the surface becomes intensely hard providing good

wear qualities. Tools made from Carbon Tool Steel can be sharpened to a keen edge with a high finish. Some special steels are made with the carbon content as low as .60% or as high as 1.40%.

The significant characteristic of Carbon Tool Steels is that differential hardening results from heat treatment. This is better described as a "case" and "core" effect.

The case is a uniformly hard, outer area which is file hard in the As-Quenched condition. The degree of hardness is in the range of Rockwell C-65/67.

The core hardens to a lesser degree—about Rockwell C-40/45. This provides support for the hard case. The relationship of case and core is illustrated in Figures 1 and 2—



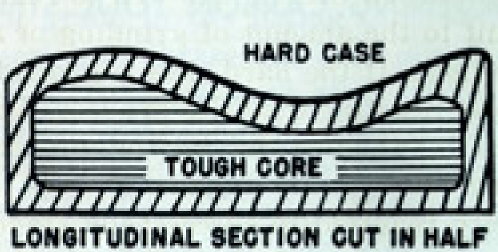


Figure 2. Cross section sketch of carbon tool steel spoon die.

While all the Carbon Tool Steels react to hardening in much the same manner, slight variations in analysis and melting practice will bring about variations in the depth of hardening or case depth. Thus, these steels are graded

as shallow, medium, medium deep, and deep hardening. The relative depth of hardness penetration (case) for each of these four grades is shown in Table I.

TABLE I — DEPTH OF HARDNESS PENETRATION (in 64ths of an inch)

	Alva Extra		*Sanderson Extra*		*Sanderson Special*	
	1450 F	*1550 F*	*1450 F*	*1550 F*	*1450 F*	*1550 F*
½" Dia.	All grades harden all the way through					
¾" Dia.	6	8	6	8	15	24
1" Dia.	5.5	7.5	6.5	8.5	12	18
1½" Dia.	5.5	7	6	8	11	15
2" Dia.	5	6	5.5	7.5	10.5	12
2½" Dia.	5	6	5	7	10	12
3" Dia.	5	6	5	7	10	11

Case Rockwell C-65/67
Case Rockwell C-40/45

It can readily be seen that Carbon Tool Steels have an outstanding characteristic in the "case-core" effect. The shallow hardening steel is of vital importance to assure the presence of the tough core in small sections. As the size increases, it is advisable to go from the shallow hardening to the medium or deep hardening steels to develop a substantial case.

In selecting Carbon Steels, it is well to remember that there is a limit to the amount of grinding or sharpening which can be done. If the hard case is ground away, the cutting or wear-resisting qualities are lost. Actually, this seldom occurs in practice due to the small amount of metal removed.

The elasticity required to successfully stand up under repeated stresses makes Carbon Tool Steels useful as blacksmith tools, cold chisels, hand punches, cold header dies, jeweler die blocks, and cold forming tools. The intensely hard case which permits sharpening to a keen edge makes them valuable for tools such as knives, razors, shears, and wood chisels.

These steels require a fast quench to obtain maximum hardness. Therefore, they are quenched in water or a water solution such as brine. A tendency to distort results with drastic quenching so that dimensional changes in tools and dies take place. Also, cracking may occur where sharp corners exist or thin and heavy sections adjoin. When design changes cannot be made, it may be necessary to go to an Oil Hardening Steel.

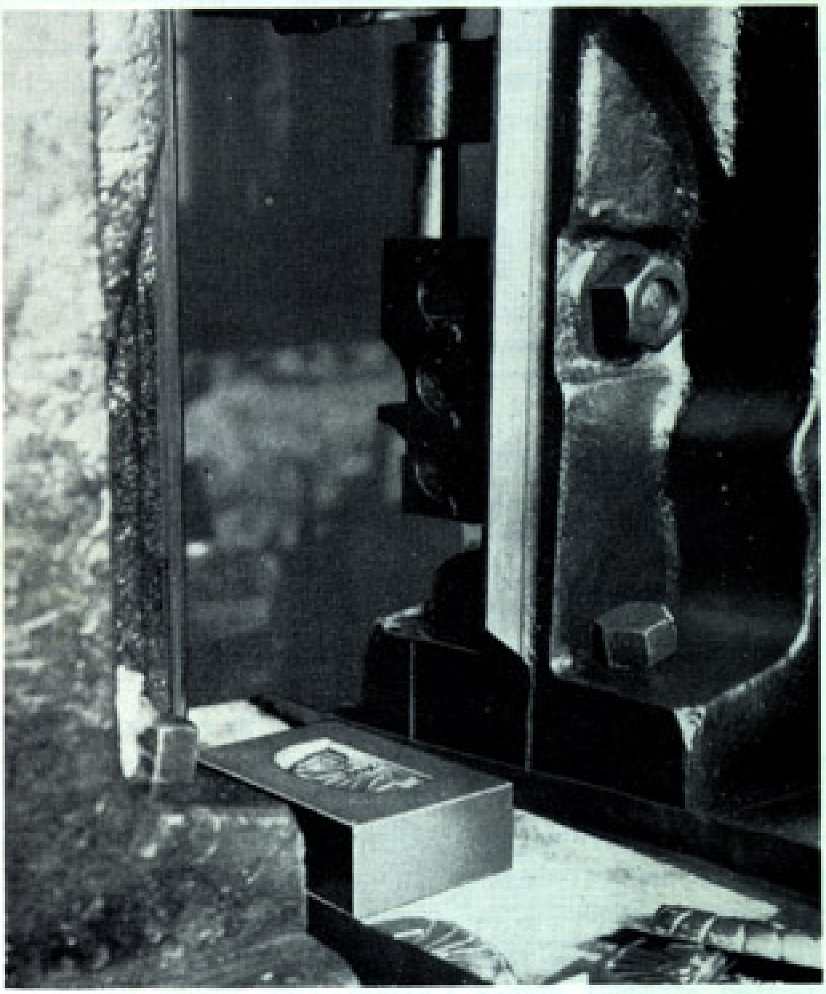


Figure 3. Water hardening tool steel in cold forming operation.

OIL HARDENING TOOL STEEL

Grade	Analysis C	Mn	Si	Cr	W
Ketos	.90	1.35	.35	.50	.50

The addition of a substantial amount of manganese plus small amounts of chromium and tungsten permits this steel to harden in oil. The "case-core" condition of the carbon tool steels disappears because Ketos will harden all the way through even in relatively large sections.

Ketos supplements the Water Hardening Steels in permitting the use of more intricate designs. Figure 4 shows samples of designs which can be safely hardened in oil,

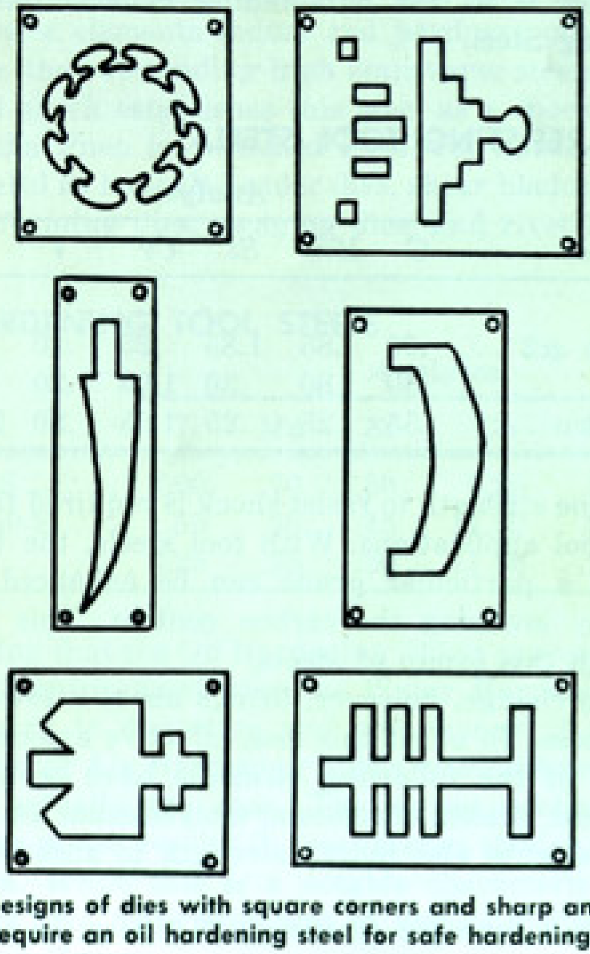


Figure 4. Designs of dies with square corners and sharp angles which require an oil hardening steel for safe hardening.

but not in water. Also, more grinding and resharpening can be accomplished with this grade because it is deeper hardening.

When the need of these features is evident, Oil Hardening Steels are used for many of the same tools as the carbon tool steels. Some of these are blanking, coining, and drawing dies. The ability to harden with less distortion makes Ketos a desirable choice for gauges, master hobs, and molding dies.

In selecting Ketos over the carbon tool steels a sacrifice, to a degree, is made with regard to edge keenness, resistance to shock, and machinability. In considering toughness, it has been found that the Oil Hardening types are superior to the carbon tool steels in equivalent sections which harden all the way through.

In practice, the overwhelming use of Ketos clearly establishes it as the outstanding general purpose Oil Hardening Steel.

SHOCK RESISTING TOOL STEELS

	Analyses						
Grade	*C*	*Mn*	*Si*	*Cr*	*V*	*W*	*Mo*
LaBelle Silicon #2 . . .	.60	.85	1.85	.25	.20	—	.30
Halvan	.50	.80	.30	1.00	.20	—	—
Atha Pneu	.55	.25	.25	1.25	.20	2.75	—

Extreme strength to resist shock is required for a number of tool applications. With tool steels, the toughness value of a particular grade can be enhanced to some extent by lowering the carbon content. This has been done with this group of steels.

Such a change, however, brings about a lower degree of hardness. To offset this loss, effective amounts of one or more of the following elements have been added—manganese, silicon, chromium, molybdenum, or tungsten. These elements also induce strength to absorb repeated stresses.

LaBelle Silicon #2 contains 1.85 silicon. In addition to

promoting hardenability, silicon gives resistance to impact and battering at a relatively high hardness. This grade will harden either in oil or in water. Simple shapes and large sections are usually water quenched. Complicated shapes and smaller sections may be oil quenched. It is frequently used for cold cutters, mauls, screw drivers, concrete breakers, shear blades, and hand chisels.

Halvan contains a substantial amount of chromium which forms hard carbides with improvements in abrasion resistance and gives this grade some capacity to resist softening when the tool temperature increases. Halvan is usually quenched in oil, but can be successfully hardened in water if the tool shape is simple. It is used for chisels, die holders, hot header dies, and rivet sets.

Atha Pneu with 2.75% tungsten and 1.25% chromium has accentuated wear resisting and cutting qualities. While these elements induce red hardness properties to a degree, the outstanding high transverse strength under repeated shock establishes this steel as a shock resisting type. Atha Pneu is quenched in oil for hardening. It is most useful as hot bolt header dies, shear blades, chipping chisels, forming dies, swaging dies, and rivet busters.

AIR HARDENING TOOL STEELS

	Analyses					
Grade	*C*	*Mn*	*Si*	*Cr*	*V*	*Mo*
Airkool-S	1.00	.70	.30	5.25	.30	1.15
Airdi 150-S	1.55	.35	.45	11.50	.90	.80
HYCC	2.25	.35	.50	11.50	.20	.80

Knowing that the Oil Hardening Steels represent a pronounced improvement over the Water Hardening Types with regard to distortion and size change, it should be expected that Air Hardening Steels would be even better. This is actually the case. The slower cooling in the hardening phase results in less intense strains with less distortion. While this is a notable characteristic, these steels are also more resistant to abrasion than the Oil Hardening Types.

In general, the most important element in making these steels air hardening is molybdenum. By uniting with the carbon and chromium, it produces hard carbides which give high wear resistance to these steels. This is of essential value because these steels are used mostly for blanking and forming dies, rolls, cams, gauges, and similar long run applications. The higher alloy content requires that the hardening temperature be raised. Vanadium is introduced to prevent grain coarsening.

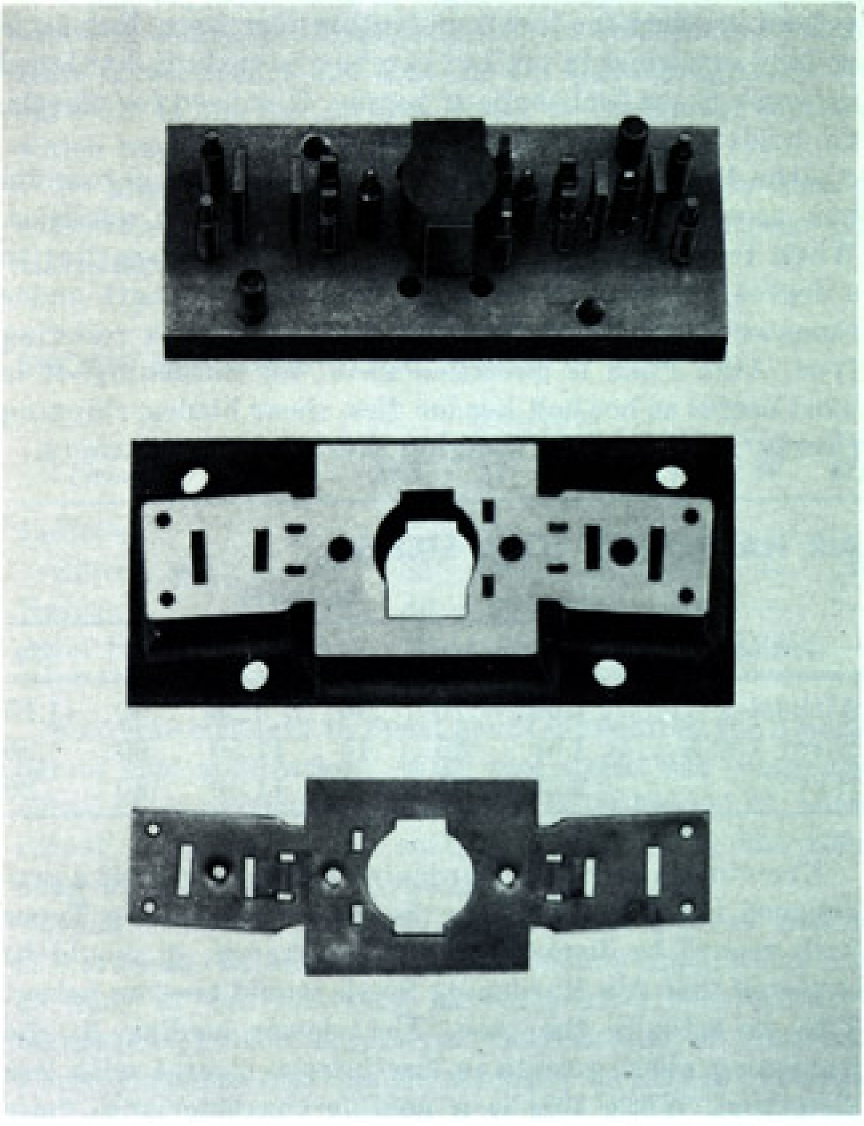


Figure 5. HYCC used for blanking with excellent control of size and high wear resistance for long production run.

Airkool-S contains the least amount of alloy of the three grades listed in this group. It is extremely tough with excellent properties of minimum distortion. It is a deep hardening steel used to replace the Oil Hardening Type when greater tool or die life is required for long production runs.

Both Airdi 150-S and HYCC contain greater amounts of carbon and chromium which result in the formation of more chromium carbides than in Airkool-S. Consequently, these grades are used when there is a need for more abrasion resistance. The 2.25% carbon grade, HYCC, is used where abrasive wear is extreme Airkool-S is used where toughness requirements are needed most. Airdi 150-S is intermediate in both respects between these two.

HOT WORK STEELS

	Analyses						
Grade	*C*	*Mn*	*Si*	*Cr*	*V*	*W*	*Mo*
Halcomb 218..	.40	.40	1.05	5.00	.50	—	1.35
Chro-Mow ...	.35	.35	1.05	5.00	.35	1.25	1.35
Peerless A	.30	.30	.30	3.35	.25	9.00	—
Rex VM, PX..	.50	.30	.30	4.00	1.95	—	8.00

Hot Work Steels, as the name implies, are used in operations where the material being worked is usually in a temperature range of 1100 F. to 2000 F. Actually, the tools and dies, themselves, become hot, reaching temperatures ranging from 600 F. to 1200 F. Typical applications are shell forging, hot extrusion, and hot shearing.

The principal requirement of these tool steels is to maintain a high hardness or resistance to softening in the temperature range mentioned. Chromium, tungsten, and molybdenum are all effective in promoting this property. They are also important in developing the necessary resistance to abrasion. As stated earlier, these elements induce deep hardening characteristics and so these steels will harden by quenching in air.

Toughness to withstand high pressures, or intermittent shock, is always a requirement of Hot Work Steels. For

this reason, the carbon content is in a range lower than any of the other groups of steels being discussed. However, carbon is present in sufficient quantity to give reasonable hardness. Silicon is also useful in promoting toughness.

In referring to Hot Work Steels, it is common practice to class them either as chromium types or tungsten types. This depends on which of these two elements predominate. Halcomb 218 and Chro-Mow are in the chromium group; Peerless A is in the tungsten group. Rex VM, PX Temper is a low carbon high speed steel used for hot work applications and does not fall into the above classification.

The chromium grades offer more resistance to repeated stresses. They will better resist heat checking from rapid temperature changes where liquid coolants are used. The tungsten types offer greater resistance to heat and abrasion. They are essentially semi-high speed steels with lower carbon content and possess much greater toughness than the high speed steels. They are usually used when the tools approach a dull red heat.

HIGH SPEED STEELS

These steels are the most highly alloyed of all the tool steel types. The name was popularly applied when it was first discovered that greatly increased cutting speeds could be used by hardening from high temperatures.

The most important feature of these steels is the ability to resist softening at elevated temperatures. Putting it another way, increased speeds of machining to the point where the tool becomes a dull red occurred with the advent of high speed steels. They have the ability under such conditions to maintain much harder cutting edges than any other tool steel.

Tungsten and molybdenum are the predominating elements in high speed steel. They have the same general effect in producing "Red Hardness" which means high hardness at elevated temperatures. They may exist singly or in combination with one another in varying percentages. When molybdenum is used in place of tungsten, the amount of molybdenum is about one-half the amount of tungsten replaced.

It is general practice to refer to a high speed steel as either a tungsten or molybdenum type depending on the predominance of either element. Those which contain 3% or more of molybdenum are classed as molybdenum types. The tungsten types usually contain more than 12% of that element.

Chromium, in conjunction with tungsten or molybdenum, improves red hardness. It also adds wear resistance by forming chromium carbides. With cobalt added, or vanadium increased, further classification of types is necessary. Cobalt, while it does not form carbides, further increases red hardness. Vanadium produces a hard carbide which is extremely abrasion resistant.

There are more than 20 grades with distinctly different analyses which are commercially available at the present time. This booklet shows 3 groups with a total of 10 grades. These 10 steels will fulfill the major requirements for high speed steels, although there are others of special analysis tailored to specific applications.

GENERAL PURPOSE HIGH SPEED STEELS

	Analyses							
Grade	*C*	*Mn*	*Si*	*Cr*	*V*	*W*	*Mo*	*Co*
Rex M2S . . .	.85	.30	.30	4.15	1.95	6.40	5.00	—
Rex TMO . .	.85	.30	.30	3.75	1.15	1.55	8.70	—
Rex VM	.90	.30	.30	4.00	1.95	—	8.00	—
Rex AA	.75	.30	.30	4.00	1.15	18.00	—	—

The basic tungsten or molybdenum types have what may be considered a normal balance of properties. Because of this, they are referred to as General Purpose High Speed Steels. The cobalt and high vanadium types accentuate specific properties and so are considered as special types.

Rex AA, the standard 18-4-1 tungsten high speed steel, was the outcome of the first work on high speed steel. Consequently, it has received the greatest attention in research development and has been used as a standard for comparison of all the other grades since shortly after the turn of the century. Today it is still widely used be-

cause it is less susceptible to decarburization than the others.

Rex M2S, Rex TMO, and Rex VM are known as molybdenum types. The development and use of this type was held back for many years because of its tendency to decarburize. The presence of molybdenum is responsible for this trait. The constant improvements in heat treating practices to overcome this drawback plus the forced familiarity due to the scarcity of tungsten and economic trends in recent years have resulted in its overwhelming acceptance.

Rex M2S is the most popular of all the Rex High Speed Steels at the present time. It differs from the 18-4-1 type in that a combination of 6½% tungsten and 5% molybdenum replaces the 18% tungsten in Rex AA. As compared to Rex AA, Rex M2S shows improvement in toughness and wear resistance. It has found widespread use as multiple point cutting tools such as drills, taps, hobs, hacksaw blades, and broaches.

Figure 6. Broaches made of Rex M-2S High Speed Steel.

Rex TMO and Rex VM both contain about 8% molybdenum. The former has 1½% tungsten while the latter

contains no tungsten. They are tough high speed steels which are used in large quantities for twist drills, taps, and cutters. Being molybdenum types they have a tendency to decarburize during heat treatment.

COBALT TYPES

	Analyses							
Grade	*C*	*Mn*	*Si*	*Cr*	*V*	*W*	*Mo*	*Co*
Rex AAA	.75	.30	.30	4.00	1.15	18.00	.75	5.00
Rex 95	.80	.30	.30	4.00	2.00	14.00	.75	5.25
Rex 49	1.10	.45	.30	4.25	2.00	6.75	3.75	5.00

Cobalt has been added to high speed steel to increase red hardness properties. About 5% is the usual addition, although some special grades contain 8% and others 12%. Abrasion resistance is improved slightly with these types, but there is a noticeable decrease in toughness. With cobalt additions there is a tendency towards decarburization in hardening.

Rex AAA (18-4-1 + 5 Co) and Rex 95 (14-4-2 + 5 Co) are tungsten-cobalt types. Both of these grades are recommended for continuous hogging cuts or where the tool must cut dry. They are usually used for single point cutting tools and, in some cases, for form tools and cutters. Rex AAA is widely used for machining cast iron and non-ferrous alloys. Rex 95 is a good choice for machining stainless steels. Rex 49 is a balanced analysis molybdenum-cobalt type and is the most outstanding high speed steel for cutting hard-to-machine materials.

HIGH VANADIUM TYPES

	Analyses						
Grade	*C*	*Mn*	*Si*	*Cr*	*V*	*W*	*Mo*
Rex 4V . . .	1.25	.30	.30	4.00	4.00	18.50	.75
Rex M3S-1.	1.05	.30	.30	4.00	2.40	6.25	6.25
Rex M3S-2.	1.20	.30	.30	4.00	3.00	6.25	6.25

By increasing the vanadium and carbon content of high speed steel it has been possible to gain a much greater number of extremely hard vanadium carbides. These types give longer wear life to tools in cutting highly abrasive materials. Raising the vanadium content over 2.00% requires an approximate increase in carbon of 0.20% for each 1.00% increase in vanadium. These types are sometimes referred to as Super High Speed Steels. Unusual performance with tool life increased as much as two or three times that of standard high speed steels is not uncommon.

Rex 4V (4% vanadium) is a tungsten-vanadium high speed steels. Rex M3S-1 (2.40% vanadium) and Rex M3S-2 (3.00% vanadium) are molybdenum-vanadium types. In choosing one of these steels, it should be borne in mind that they grind with greater difficulty in the hardened condition. This is to be expected, since they have greater resistance to abrasion.

Rex M2S, M3S-1, and Rex M3S-2 contain higher amounts of sulfur than normal in order to make them easier to machine and grind. A definite improvement in machinability and grindability has been found with no serious loss in toughness. Many years of experience have indicated no impairment in cutting ability.

HEAT TREATMENT OF TOOL STEELS

The intrinsic value of tool steels becomes a reality only after heat treatment. Therefore, it is extremely important that the best job possible be done to get maximum performance. The cost of shaping tools is usually quite high making it penny-wise and dollar-foolish to try to cut corners or take short cuts.

The heat treater is not being tempermental when he says one job will take longer than another. Actual differences exist in the correct procedure for the various types and grades of tool steels. As a rule, the more alloy in a tool steel, the longer it will take to harden the steel properly. Generally speaking, it is also true that the hardening temperature will be higher.

Figure 7. Hardening Rex High Speed Steel Bits.

When discussing the heat treatment of tool steels, the basic concept is hardening followed by tempering. Hardening consists of heating to a prescribed temperature to condition the steel for quenching, and then cooling at a predetermined rate usually to just above or near room temperature.

The temperature of the preheat will vary depending on the type of steel, but it is generally above 1000 F. and seldom over 1600 F. High hardening temperatures and large or irregular sections will indicate the need for preheating. In many instances, it is not necessary to preheat Carbon Tool Steels, Ketos, and some of the Shock Resisting Steels unless the sections are large. If unusually large sections are encountered, it may be wise to employ two preheating steps.

High Heat

The high heat cycle is the most important one. At this point, the final conditioning of the steel preparatory to quenching is accomplished. Not only is the temperature important, but the time must also be carefully watched. Excessive time or temperature will cause grain coarsening and decarburization. There is a reasonable leeway for control of both conditions. Low temperatures or short times bring about inadequate solution of carbides or non-uniform structural conditions.

Frequently, a "soak" at the high heat temperature is specified. This means that the steel must be held at the quenching temperature for a certain period of time. There are two reasons for this: first, it assures the entire section being thoroughly heated; second, the more highly alloyed steels, particularly the air hardening and hot work steels, are somewhat sluggish in responding to heat treatment and require time for conditioning.

Quench

When the high heat cycle is complete, the work is removed for quenching. The actual hardening of the steel takes place during the quench. The change progresses as the temperature decreases within a range of 700 F. to 400 F. on down below 150 F. where the reaction is sufficiently complete from a practical viewpoint.

Various compositions require different cooling rates to assure full hardness. The decision to use a particular quenching medium is based on its ability to remove heat at the rate required by the particular steel and the mass of the section. The ideal medium would reduce the tem-

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High Heat

The high heat cycle is the most important one. At this point, the final conditioning of the steel preparatory to quenching is accomplished. Not only is the temperature important, but the time must also be carefully watched. Excessive time or temperature will cause grain coarsening and decarburization. There is a reasonable leeway for control of both conditions. Low temperatures or short times bring about inadequate solution of carbides or non-uniform structural conditions.

Frequently, a "soak" at the high heat temperature is specified. This means that the steel must be held at the quenching temperature for a certain period of time. There are two reasons for this: first, it assures the entire section being thoroughly heated; second, the more highly alloyed steels, particularly the air hardening and hot work steels, are somewhat sluggish in responding to heat treatment and require time for conditioning.

Quench

When the high heat cycle is complete, the work is removed for quenching. The actual hardening of the steel takes place during the quench. The change progresses as the temperature decreases within a range of 700 F. to 400 F. on down below 150 F. where the reaction is sufficiently complete from a practical viewpoint.

Various compositions require different cooling rates to assure full hardness. The decision to use a particular quenching medium is based on its ability to remove heat at the rate required by the particular steel and the mass of the section. The ideal medium would reduce the tem-

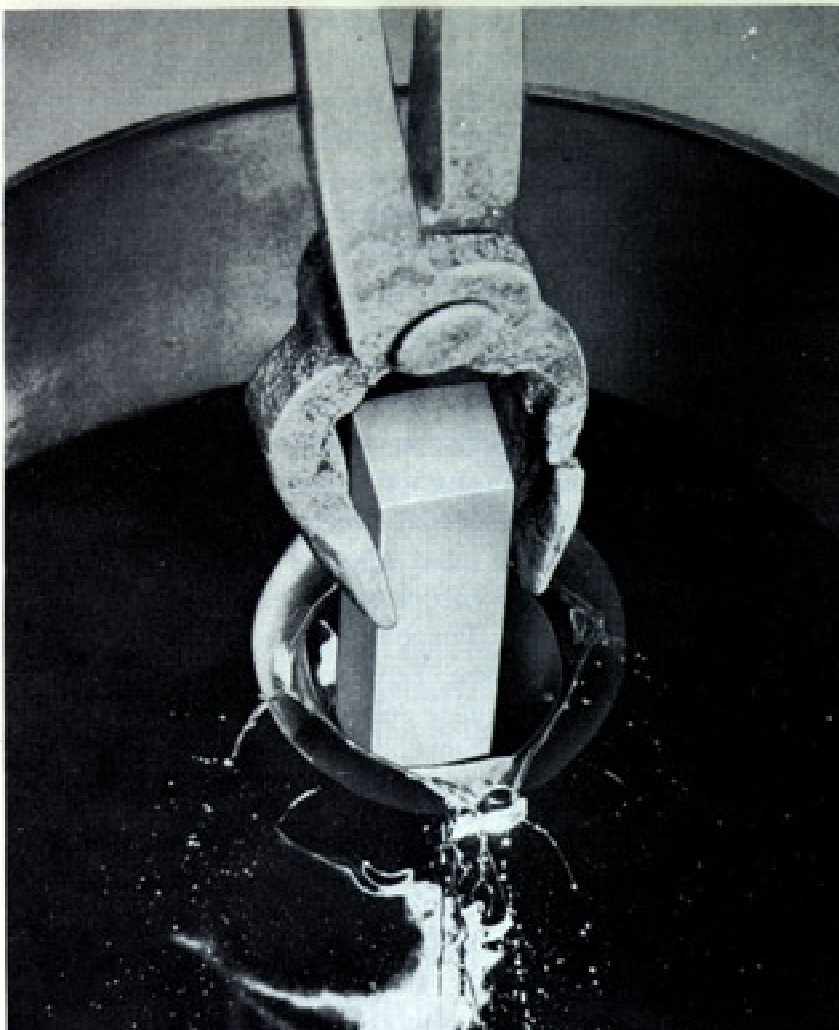

Figure 8. Quenching steel in water.

perature quickly at first and then more slowly to accommodate the stresses from hardening which develop in the lower temperature range.

Temper

Tempering follows the quench. While this step is the simplest and easiest to perform, its importance is not minor. Again, we have a time-temperature relationship which requires exact control of both. Control of the time between the quench and temper is vital.

Since hardening takes place gradually at the end of the quench cycle, it is readily apparent that tempering too

soon interrupts cooling putting a stop to further hardening. In large sections where a decided temperature

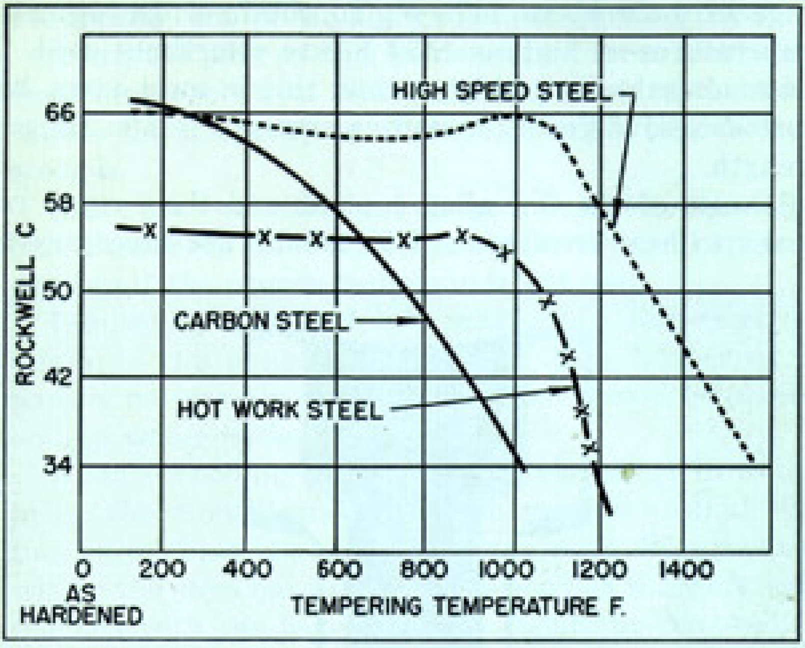

Figure 9. Hardness versus tempering temperature for three grades representative of Carbon, Hot Work, and High Speed Steel.

gradient exists, cracking may occur. Even if this does not happen, the hardening will not be complete.

On the other hand, if the work is permitted to lay around at room temperature, the stresses from hardening continue to build up to a point where rupture may occur. These conditions show the need for definite timing at this stage. The long standing rule of tempering as soon as the work can be held with the bare hand continues to be a good guide.

The usual range for tempering spreads from 300 to 1200 F. depending on the grade and hardness desired. The time should be a minimum of one hour and may extend as long as six hours in some cases. The response to tempering is slow, requiring a full measure of time for completeness. For the higher alloyed steels which generally are hardened from temperatures above 1700 F. double tempering is essential to achieve the full benefit from this treatment. Figure 9 shows the general effects on hardness after tempering three grades representative of the types shown.

WATER HARDENING CARBON TOOL STEELS

Carbon Tool Steels are generally hardened from a range of 1420 F. to 1475 F. To obtain a deeper case, temperatures as high as 1550 F. are sometimes used. It is not advisable to go higher than this in most cases, because excessive grain coarsening causes a loss in fatigue strength.

Because of the low alloy content and their rapid response to heat treatment, it is usually not necessary to

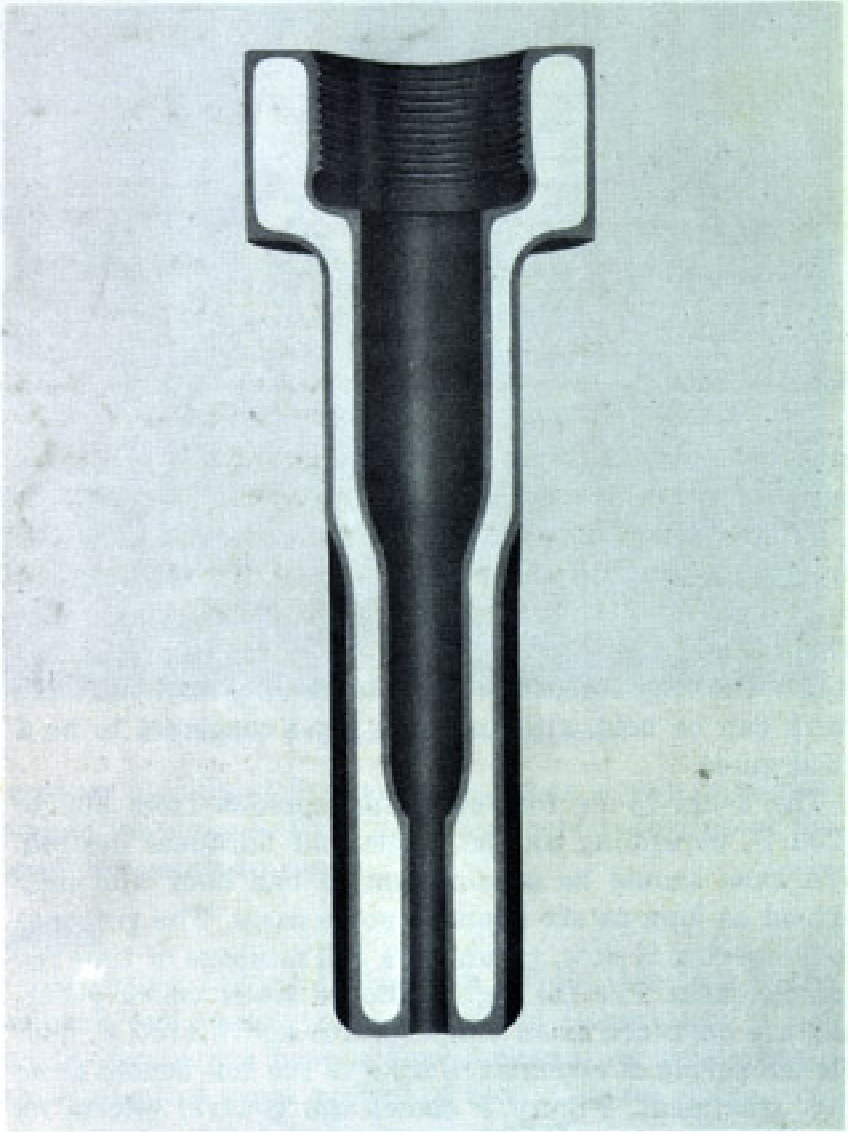

Figure 10. "Case-Core" of split piston made of water hardening carbon tool steel.

preheat these steels. However, it is advisable to preheat large tools as it will help in heating more uniformly and reduce the time in the higher temperature furnace.

A critical part of the hardening of these steels is the quenching operation. Water quenching is drastic and will reduce the temperature of the tool or die in a matter of seconds.

There are two attendant dangers in water quenching—one, a tendency for the steel to crack; two, soft spots may develop if the proper technique is not used.

Tempering should follow quenching immediately to minimize the danger of cracking. If a tempering furnace is not readily available, the tool should be placed in boiling water without delay.

When quenching Carbon Tool Steels, either in water or brine, the work should remain submerged until all vibration stops. This is a signal that the most violent changes within the steel have stopped. As soon as the work can be touched with the bare hands, it should be removed. The belief that the tool or die must be stone cold to get full hardness is erroneous. Such a practice invites cracking.

Soft spots cause a break in the uniformity of the hardened surface. As weak links in a strong chain, they spell failure. They develop in two ways—either the surface temperature is lowered just prior to quenching or areas on the surface become insulated from the quenching medium.

Premature splashing or contact with tongs or fixture parts will cause the surface temperature to drop in localized points. Steam or air bubbles, dirt, scale, or oil in the quenching bath, are all sources of insulation. These insulators prevent the water or brine from contacting the area while the temperature is still high enough to bring about full hardness.

Good housekeeping to keep the quenching medium clean and the use of common sense in understanding what is taking place makes the hardening of these steels practical for a wide variety of uses.

Where maximum hardness is desired, the lowest safe tempering temperature is that of boiling water. Except for work such as burnishing rolls, this low temperature

is not usually applied. For general tool and die work, the normal tempering temperature is within 350 F. to 400 F. For those tools subject to impact, such as chisels and rivet busters, temperatures between 550 F. to 600 F. are used.

OIL HARDENING TOOL STEEL

Ketos is hardened in much the same manner as the Carbon Tool Steels except oil is used as the quenching medium. The normal hardening range is slightly higher, usually 1450 F. to 1500 F. Preheating at 1200 F. to 1250 F. is recommended for large or intricate sections.

For quenching, warm thin oil should be used to bring the temperature below 150 F. or until the work can be held in the bare hands. Where minimum size change is desired, the parts may be removed from the oil just under the flash point (about 400 F.) and allowed to cool in air below 150 F.

Tempering should be done immediately. If there must be a delay, the use of boiling water is recommended. The usual hardness required is Rockwell C-60/62. This can be obtained by tempering within the range of 350 F. to 400 F. for a minimum of two hours. Sections over two inches thick should be tempered a minimum of one hour per inch.

SHOCK RESISTING TOOL STEELS

As a group these steels are not associated with a distinctive quenching medium, since LaBelle Silicon #2 and Halvan may be hardened in either oil or water while Atha Pneu is an oil hardening grade. LaBelle Silicon #2 is more susceptible to decarburization than the others.

AIR HARDENING TOOL STEELS

This group of steels hardens in air by cooling from a temperature range of 1800 F. to 1850 F. Preheating within a range of 1450 F. to 1500 F. is common practice. The usual hardness, obtained by tempering at 400 F. to 600 F., is Rockwell C-58/62.

Because of the high temperatures used in hardening, these steels should be heated in atmosphere controlled furnaces to avoid decarburization and pitting. If such furnaces are not available, the work should be wrapped in brown paper and packed in an inert material such as clean, dry cast-iron chips or a commercial *neutral* packing compound.

To gain maximum hardness, they are sometimes quenched in oil. When this is done, the high heat temperature is dropped to a lower range of 1750 F. to 1800 F. To avoid excess scaling in air, tools are sometimes flash quenched in oil to about 1000 F. to 1200 F. and then cooled in air.

Adequate space should be allowed to afford a uniform movement of air around the parts being cooled. It is not good practice to use forced air although a mild flow of air from an electric fan is often used to speed up the cooling action.

HOT WORK STEELS

Since this group is comprised of two principal types, the Chromium and Tungsten Hot Work Steels, it is expedient to show the usual hardening cycles as in Table II.

TABLE II

	Chromium	*Tungsten*
Preheat	1400/1500 F.	1500/1550 F.
High Heat ..	1800/1850 F.	2150/2250 F.
Quench	Air Cool below 150 F.	Interrupted Oil Quench to 1000 F., then Air Cool below 150 F.
Temper	1050 F.	1200 F.
Rockwell C ..	45/50	40/45

Double tempering of these types is essential. In double tempering, the steel is heated to the desired temperature, held for the required time, allowed to cool to room temperature, and then reheated and cooled through the same cycle. The tempering temperature used should be higher than that which the tool is expected to reach during the actual operation.

The surface of the chromium steels needs protection during heat treatment either by atmosphere control or pack hardening as described under air hardening steels.

HIGH SPEED STEELS

These steels require high temperatures for hardening. The molybdenum types are usually hardened from a range of 2200 F. to 2250 F., the tungsten types as a rule from 2300 F. to 2350 F., when heat treated in an atmosphere controlled furnace. When salt baths are used, the temperature is lowered 25/35° F. Both types should be preheated within the range of 1450 F. to 1550 F. In high production units, savings will be realized if a double preheat such as 1200 F. and then 1550 F. is used.

There are two predominant aims in heat treating high speed steels. One is to develop maximum red hardness and resistance to abrasion. In such cases, the ideal practice is to heat the steel to the high side of the range and quench in oil. This procedure allows the maximum solution of hard carbides to take place without excessive grain coarsening or the development of a duplex grain size. With this technique, hardness values of about Rockwell C-65 are consistently obtained, but toughness (the ability of the cutting edge to withstand operating stresses without chipping) is sacrificed to a degree. However, this treatment is practical for single point tools and inserts where the cutting edges are well supported.

The other aim is to accent toughness in order to prevent the early failure of tools by chipping. To achieve this condition, lower hardening temperatures are recommended in conjunction with salt bath quenching or air cooling. Temperatures as much as 100 F. to 200 F. lower than normal are often used. Hardening in this manner will result in hardness values of Rockwell C-62/64. Small, multiple point tools, such as drills, end mills, taps, and hacksaw blades, require accentuated toughness. Other tools such as punches and billeteer tools where shock is pronounced are also heat treated in this way.

Generally, high speed steel is quenched in a liquid bath, either salt or oil. To minimize distortion, air cooling is sometimes used. Water should *not* be used because its fast

action invariably results in cracking even in small sections.

Liquid salt bath quenching is quite common where the complete installation for hardening consists of a battery of salt bath furnaces. The piece being hardened is quenched into a bath operating at about 1100 F. An important point to consider is the control of heat being absorbed in the quenching bath to prevent the temperature from exceeding 1200 F. After the temperature of the piece has equalized throughout, the piece is removed from the bath and cooled in air to about 150 F. and immediately tempered.

Oil quenching is more effective and should be used when maximum hardness is the aim. The piece is either quenched directly into oil at about 150 F. or the "interrupted" quench is used. The latter is the best and preferred procedure. To accomplish this the work is plunged into the oil until the color disappears from the surface. Then the tool is removed and held in the air until the color reappears on the surface. It is usually necessary to repeat this a number of times, depending on the size of the work, until the color becomes a uniform dark red. The tool is then allowed to finish cooling in air. As in the case of Hot Work Steels, High Speed Steels should be double tempered.

HEAT TREATING TECHNIQUE

The previously described procedures are "general" since they apply to a number of individual steels in a family grouping. Precise temperature ranges for each grade have not been shown. To use these recommendations requires a certain amount of heat treating "know-how." Like so many other skills, there just isn't any published manual which covers the practical "tricks of the trade." In the absence of such a manual, several recommendations are offered as a guide for each heat treater to establish his own "bible" as a supplement to his every day experience.

RECORDS

The recording of data pertaining to the heat treating of specific tools is commonly practiced. Actually, the recorded notes represent an interpretation of metallurgical science.

One of the primary values of individual notes is that

the information relates to the equipment at hand. There are also many other values—practical results to compare with laboratory reports, ready reference for repeat jobs which only occur at long intervals, and a history of the job to correlate with field performance. In this latter respect, good notes serve as useful evidence to determine the reasons for unusual performance, either good or bad.

In addition to this personal record, the heat treater's library should include data sheets of tool steels, booklets and preprints of articles, as well as bulletins relating to heat treating equipment and supplies.

INSPECTION OF INCOMING MATERIAL

The first contact with the work, as it arrives in the Hardening Room, is a good time to give some thought to what is going to happen. Usually tool steel, ready for heat treatment, will be in the annealed condition with the

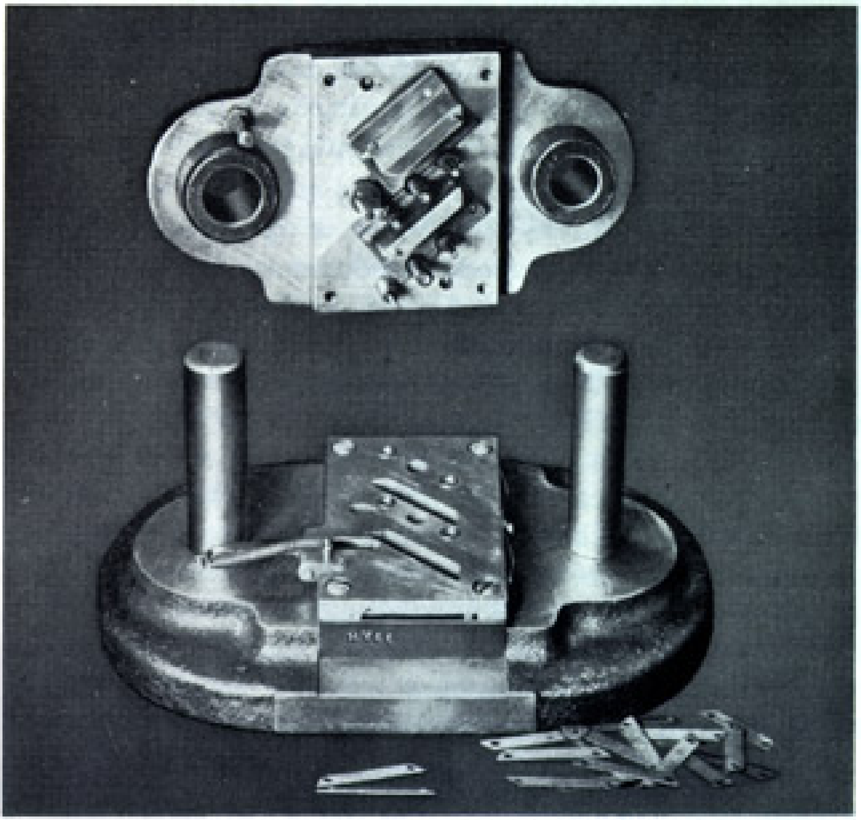

Figure 11. Blanking die of HYCC properly identified before heat treatment.

mill surface removed. Of course, the steel in one way or another will have been formed into a particular shape.

A look at the tool or die will often tell the condition of the material to indicate whether or not a successful hardening operation can be accomplished, and certainly the work should be clearly marked with the brand name or symbol of the tool steel type *(Figure 11)*. Such things as sharp corners, variation in thickness, shiny streaks from cold working, original bar surface, excessive burning from grinding, or tool marks all tell a story. As experience is accumulated, the ability to detect grade mix-up or improper hardness as revealed by a machined surface will prevent many tool failures.

If inspection of the material in any way suggests a cause for hardening difficulty, a careful review should be made. Hardness may require checking, or a spark test to identify the material may be necessary. Frequently, such faulty results as hardening cracks, low hardness, size change, coarse grain, and distortion are traced to conditions which existed prior to hardening. It isn't only spoilage of expensive tools which is involved, but production may be halted or delayed due to a lack of tools.

PREPARATION

While the work is being inspected, plans for outlining the heat treating cycles can be made. Some cycles are long, and close timing for the best use of a variety of heat treating equipment requires good planning. With tool steels, no part of the operation should be left to chance nor should the heat treater get himself into a dilemma for want of preparation. In some cases, it may be worthwhile to make a "dry run" to insure the best results.

In addition to arranging fixtures, tongs, and other handling equipment, it is sometimes necessary to pack the work for protection against furnace atmospheres. Cast-iron chips are commonly used for this purpose. This is an excellent material for the job, but trouble can occur if the chips are not properly conditioned. They are first cleaned free of dirt and oil, and then burned or "spent" to remove the carbon. This makes them inert. It is im-

portant that all packing mediums be kept dry; otherwise, decarburization and scaling will result.

In preparing a pack, the work is wrapped in heavy wrapping paper before being placed in the box. The paper chars and prevents the chips from sticking to the work. The layer of chips lining the box should be 1½" to 2" thick. There are also several commercial compounds for this purpose. The important feature is to be sure that they are inert.

TESTING

To check results of hardening, the heat treater should be familiar with several practical test procedures. File testing, Rockwell hardness testing, and sandblasting to check soft spots are quick methods for obtaining indications of the response to heat treatment.

The file hardness test is used to determine if the heat treated product is "file hard." The best time to use this test is after hardening but before tempering. The reason for this is that this test is specifically associated with "full hardness" and tempering usually softens the steel.

In file testing, a firm pressure on the flat (not the edge) of the test file is required with a slow forward stroke. In most cases, a shallow skin (tenths of thousands) will be present on the work. The file will quickly bite through this and then slide over the hard area. If the work is not "full hard" or decarburization is present, the file will drag and remove appreciable amounts of metal.

The test file is a standard product made specifically for this purpose. A good description of the file test is given in the ASM Metals Handbook. If much filing is done on hard steel, the test file quickly loses its sensitivity and usefulness because the sharp edges on the teeth wear off leaving the file dull.

The Rockwell Hardness Tester *(Figure 12)*, is universally used for testing hardened tool steels. The most important fact to remember is that the hardness values, in themselves, are not positive indications but are relative. When compared with technical reports and data from previous field experience, they will indicate if the aims of heat treatment have been realized.

Figure 12. Rockwell Hardness Tester.

It is not always practical or possible to make a hardness test on the material itself. For this reason, the use of pilot samples for test purposes is highly recommended. Not only can hardness tests be made, but the samples can be broken for visual inspection of the grain size or the sample may be used for examination under the microscope.

Surface inspection to determine soft spots is often made after sandblasting. This is especially useful with Carbon Tool Steels to determine the effectiveness of the quench. Areas which are soft will be dull because the abrasive will have penetrated the surface more than in the hard areas. Variations of the finish due to differences in hardness are readily distinguished. This inspection is also useful in determining the presence of tight scale.

HEATING EQUIPMENT

Furnace equipment for heating tool steels includes salt baths, atmosphere controlled furnaces, and muffle type furnaces. At one time, salt baths were looked upon as a cure-all to avoid decarburization, carburization, pitting, and poor surface conditions in general. The idea existed that no change in the surface was possible because there was no contact between the work and a gaseous atmosphere.

This is an erroneous conception because oxides in the

bath will attack the steel. On the other hand, salt baths definitely represent a means of positive control as far as surface is concerned, but maintenance of the neutral condition of the salt requires close attention. Desludging, additions of fresh salt, the use of graphite rods, and other rectifiers are all used on a regular schedule to keep the bath clean.

Each type of heating medium has its particular advantages and disadvantages, but to get clean work without surface attack requires religious control no matter what type of furnace is used. An important consideration in selecting a type of furnace concerns the requirements to properly fixture or support the work.

Flame hardening and induction heating, which are well known, are seldom used with tool steels. With these methods, positive control of temperature is not possible, and the fast rates of heating result in undesirable temperature differentials. In some special cases, they may be used with small sections.

Martempering, austempering, carburizing, and nitriding are other heat treating processes used in connection with tool steels. Because of their rather special application, they are not discussed in this booklet.

There are also operations such as forging, grinding, and machining which are important in considering the use of tool steels, but are not discussed in this booklet. These are mentioned solely to recall that this discussion of tool steels is of a general nature.

At the present time, all of us are digging in to lower manufacturing costs. As the major producer of tool steel, Crucible is eager to give specialized service to insure maximum performance from its products. The user should not wait until trouble develops, but should plan periodic review for adjusting outmoded practices before serious situations develop.

In recognizing the need for even greater attention, Crucible has Industry Specialist and Field Technical Service Engineers to augment and act as a liaison between Sales, Operations, Metallurgy, and Research Laboratories. The activities of these people are directed primarily in the field of application.

USEFUL INFORMATION

To find circumference of a circle multiply diameter by 3.1416.

To find diameter of a circle multiply circumference by .31831.

To find area of a circle multiply square of diameter by .7854.

Area of rectangle. Length multiplied by breadth. Doubling the diameter of a circle increases its area four times.

To find area of a triangle multiply base by ½ perpendicular height.

To find surface of a ball multiply square of diameter by 3.1416.

To find side of an inscribed square multiply diameter by 0.7071 or multiply circumference by 0.2251 or divide circumference by 4.4428.

To find side of an equal square multiply diameter by .8862.

Square. A side multiplied by 1.4142 equals diameter of its circumscribing circle.

A side multiplied by 4.443 equals circumference of its circumscribing circle.

A side multiplied by 1.128 equals diameter of an equal circle.

A side multiplied by 3.547 equals circumference of an equal circle.

Square inches multiplied by 1.273 equals circle inches of an equal circle.

To find cubic inches in a ball multiply cube of diameter by .5236.

To find cubic contents of a cone, multiply area of base by ⅓ the altitude.

Doubling the diameter of a pipe increases its capacity four times.

A gallon of water (U. S. Standard) weighs 8⅓ lb. and contains 231 cubic inches.

USEFUL INFORMATION—*Continued*

A cubic foot of water contains 7½ gallons, 1728 cubic inches, and weighs 62½ lb.

To find the pressure in pounds per square inch of a column of water multiply the height of the column in feet by .434.

Steam rising from water at its boiling point 212 (degrees) has a pressure equal to the atmosphere (14.7) lb. to the square inch.

A standard horsepower:—The evaporation of 30 lb. of water per hour from a feed water temperature of 100 F. into steam at 70 lb. gauge pressure.

To find capacity of tanks any size: given dimensions of a cylinder in inches, to find its capacity in U. S. gallons: square the diameter, multiply by the length and by .0034.

To ascertain heating surface in tubular boilers, multiply ⅔ the circumference of boiler by length of boiler in inches and add to it the area of all the tubes.

One-sixth of tensile strength of plate multiplied by thickness of plate and divided by one-half the diameter of boiler gives safe working pressure for tubular boilers. For marine boilers add 20 per cent for drilled holes.

To find the capacity of an air compressor in cubic feet of free air per minute: Multiply the area of low pressure cylinder (on compound compressor), or area of simple compressor cylinder in square inches, by the stroke in inches and divide by 1728; and multiply this result—

(a) In single acting, simple or compound, by the R.P.M.

(b) Double acting, simple or compound, by 2 x R.P.M.

(c) Duplex double acting, by 4 x R.P.M.

LENGTH CONVERSIONS

Based on Value 1 m. = 39.37 in.

In. = *Mm.* = *Feet* = *M.* = *Yd.* = *Miles* = *Km.* =	*milli-meters*	*inches*	*meters*	*feet*	*meters*	*yards*	*kilometers*	*miles*
1	25.400 1	0.039 370	0.304 801	3.280 83	0.914 402	1.093 61	1.609 35	0.621 37
2	50.800 1	0.078 740	0.609 601	6.561 67	1.828 80	2.187 22	3.218 69	1.242 74
3	76.200 2	0.118 110	0.914 402	9.842 50	2.743 21	3.280 83	4.828 04	1.864 11
4	101.600	0.157 480	1.219 20	13.123 3	3.657 61	4.374 44	6.437 39	2.485 48
5	127.000	0.196 850	1.524 00	16.404 2	4.572 01	5.468 06	8.046 74	3.106 85
6	152.400	0.236 220	1.828 80	19.685 0	5.486 41	6.561 67	9.656 08	3.728 22
7	177.800	0.275 590	2.133 60	22.965 8	6.400 81	7.655 28	11.265 4	4.349 59
8	203.200	0.314 960	2.438 40	26.246 7	7.315 21	8.748 89	12.874 8	4.970 96
9	228.600	0.354 330	2.743 21	29.527 5	8.229 62	9.842 50	14.484 1	5.592 33
10	254.001	0.393 700	3.048 01	32.808 3	9.144 02	10.936 1	16.093 5	6.213 70
11	279.401	0.433 070	3.352 81	36.089 2	10.058 4	12.029 7	17.702 8	6.835 07
12	304.801	0.472 440	3.657 61	39.370 0	10.972 8	13.123 3	19.312 2	7.456 44
13	330.201	0.511 810	3.962 41	42.650 8	11.887 2	14.216 9	20.921 5	8.077 81
14	355.601	0.551 180	4.267 21	45.931 7	12.801 6	15.310 6	22.530 9	8.699 18
15	381.001	0.590 550	4.572 01	49.212 5	13.716 0	16.404 2	24.140 2	9.320 55
16	406.401	0.629 920	4.876 81	52.943 3	14.630 4	17.497 8	25.749 6	9.941 92
17	431.801	0.669 290	5.181 61	55.774 2	15.544 8	18.591 4	27.358 9	10.563 3
18	457.201	0.708 660	5.486 41	59.055 0	16.459 2	19.685 0	28.968 2	11.184 7
19	482.601	0.748 030	5.791 21	62.335 8	17.373 6	20.778 6	30.577 6	11.806 0
20	508.001	0.787 400	6.096 01	65.616 7	18.288 0	21.872 2	32.186 9	12.427 4
21	533.401	0.826 770	6.400 81	68.896 5	19.202 4	22.965 8	33.196 3	13.048 8
22	558.801	0.866 140	6.705 61	72.178 3	20.116 8	24.059 4	35.405 6	13.670 1
23	584.201	0.905 510	7.010 41	75.459 2	21.031 2	25.153 1	37.015 0	14.291 5
24	609.601	0.944 880	7.315 21	78.740 0	21.945 6	26.246 7	38.624 3	14.912 9
25	635.001	0.984 250	7.620 02	82.020 8	22.860 0	27.340 3	40.233 7	15.534 2
26	660.401	1.023 62	7.924 82	85.301 7	23.774 4	28.433 9	41.843 0	16.155 6
27	685.801	1.062 99	8.229 62	88.582 5	24.688 9	29.527 5	43.452 4	16.777 0
28	711.201	1.102 36	8.534 42	91.863 3	25.603 3	30.621 1	45.061 7	17.398 4
29	736.601	1.141 73	8.939 22	95.144 2	26.517 7	31.714 7	46.671 1	18.019 7
30	762.002	1.181 10	9.144 02	98.425 0	27.432 1	32.808 3	48.280 4	18.641 1
31	787.402	1.220 47	9.448 82	101.706	28.346 5	33.901 9	49.889 8	19.262 5
32	812.802	1.259 84	9.753 62	104.987	29.260 9	34.995 6	51.499 1	19.883 8
33	838.202	1.299 21	10.058 4	108.268	30.175 3	36.089 2	53.108 5	20.505 2
34	863.602	1.338 58	10.363 2	111.548	31.089 7	37.182 8	54.717 8	21.126 6
35	889.002	1.377 95	10.668 0	114.829	32.004 1	38.276 4	56.327 2	21.747 9
36	914.402	1.417 32	10.972 8	118.110	32.918 5	39.370 0	57.936 5	22.369 3
37	939.802	1.456 69	11.277 6	121.391	33.832 9	40.463 6	59.545 8	22.990 7
38	965.202	1.496 06	11.582 4	124.672	34.747 3	41.557 2	61.155 2	23.612 1
39	990.602	1.535 43	11.887 2	127.953	35.661 7	42.650 8	62.764 5	24.233 4
40	1 016.00	1.574 80	12.192 0	131.233	36.576 1	43.744 4	64.373 9	24.854 8
41	1 041.40	1.614 17	12.496 8	134.514	37.490 5	44.838 1	65.983 2	25.476 2
42	1 066.80	1.653 54	12.801 6	137.795	38.404 9	45.931 7	67.592 6	26.097 5
43	1 092.20	1.692 91	13.106 4	141.076	39.319 3	47.025 3	69.201 9	26.718 9
44	1 117.60	1.732 28	13.411 2	144.357	40.233 7	48.118 9	70.811 3	27.340 3
45	1 143.00	1.771 65	12.716 0	147.638	41.148 1	49.212 5	72.420 6	27.961 6
46	1 168.40	1.811 02	14.020 8	150.918	42.062 5	50.306 1	74.030 0	28.583 0
47	1 193.80	1.850 39	14.325 6	154.199	42.976 9	51.399 7	75.639 3	29.204 4
48	1 219.20	1.889 76	14.630 4	157.480	43.891 3	52.493 3	77.248 7	29.825 8
49	1 244.60	1.929 13	14.935 2	160.761	44.805 7	53.586 9	78.858 0	30.447 1
50	1 270.00	1.968 50	15.240 0	164.042	45.720 1	54.680 6	80.467 4	31.068 5

From "Ready Reference Tables," courtesy Carl Hering.

LENGTH CONVERSIONS—*Continued*

Based on Value 1 m. = 39.37 in.

In. = / *Mm.* = / *Feet* = / *M.* = / *Yd.* = / *Miles* = / *Km.* =	milli-meters	inches	meters	feet	meters	yards	kilometers	miles
51	1 295.40	2.007 87	15.544 8	167.323	46.634 5	55.774 2	82.076 7	31.689 9
52	1 320.80	2.047 24	15.849 6	170.603	47.548 9	56.867 8	83.686 1	32.311 2
53	1 346.20	2.086 61	16.154 4	173.884	48.463 3	57.961 4	85.295 4	32.932 6
54	1 371.60	2.125 98	16.549 2	177.165	49.377 7	59.055 0	86.904 7	33.554 0
55	1 397.00	2.165 35	16.764 0	180.446	50.292 1	60.148 6	88.514 1	34.175 3
56	1 422.40	2.204 72	17.068 8	183.727	51.206 5	61.242 2	90.123 4	34.796 7
57	1 447.80	2.244 09	17.373 6	187.008	52.120 9	62.335 8	91.732 8	35.418 1
58	1 473.20	2.283 46	17.678 4	190 288	53.035 3	63.429 4	93.342 1	36.039 5
59	1 498.60	2.322 83	17.983 2	193.569	53.949 7	64.523 1	94.951 5	36.660 8
60	1 524.00	2.362 20	18.288 0	196.850	54.864 1	65.616 7	96.560 8	37.282 2
61	1 549.40	2.401 57	18.592 8	200.131	55.778 5	66.710 3	98.170 2	37.903 6
62	1 574.80	2.440 94	18.897 6	203.412	56.692 9	67.803 9	99.779 5	38.524 9
63	1 600.20	2.480 31	19.202 4	206.693	57.607 3	68.897 5	101.389	39.146 3
64	1 625.60	2.519 68	19.507 2	209.973	58.521 7	69.991 1	102.998	39.767 7
65	1 651.00	2.559 05	19.812 0	213.254	59.436 1	71.084 7	104.608	40.389 0
66	1 676.40	2.598 42	20.116 8	216.535	60.350 5	72.178 3	106.217	41.010 4
67	1 701.80	2.637 79	20.421 6	219.816	61.264 9	73.271 9	107.826	41.631 8
68	1 727.20	2.677 16	20.726 4	223.097	62.179 3	74.365 6	109.436	42.253 2
69	1 752.60	2.716 53	21.031 2	226.378	63.093 7	75.459 2	111.045	42.874 5
70	1 778.00	2.755 90	21.336 0	229.658	64.008 1	76.552 8	112.654	43.495 9
71	1 803.40	2.795 27	21.640 8	232.939	64.922 5	77.646 4	114.264	44.117 3
72	1 828.80	2.834 64	21.945 6	236.220	65.836 9	78.740 0	115.873	44.738 6
73	1 854.20	2.874 01	22.250 4	239.501	66.751 3	79.833 6	117.482	45.360 0
74	1 879.60	2.913 38	22.555 2	242.782	67.665 7	80.927 2	119.092	45.981 4
75	1 905.00	2.952 75	22.860 0	246.063	68.580 1	82.020 8	120.701	46.602 7
76	1 930.40	2.992 12	23.164 8	249.343	69.494 5	83.114 4	122.310	47.224 1
77	1 955.80	3.031 49	23.469 6	252.624	70.408 9	84.208 1	123.920	47.845 5
78	1 981.20	3.070 86	23.774 4	255.905	71.323 3	85.301 7	125.529	48.466 9
79	2 006.60	3.110 23	24.079 2	259.186	72.237 7	86.395 3	127.138	49.088 2
80	2 032.00	3.149 60	24.384 0	262.467	73.152 1	87.488 9	128.748	49.709 6
81	2 057.40	3.188 97	24.688 8	265.748	74.066 5	88.582 5	130.357	50.331 0
82	2 082.80	3.228 34	24.993 6	269.028	74.981 0	89.676 1	131.966	50.952 3
83	2 108.20	3.267 71	25.298 4	272.309	75.895 4	90.769 7	133.576	51.573 7
84	2 133.60	3.307 08	25.603 3	275.590	76.809 8	91.863 3	135.185	52.195 1
85	2 159.00	3.346 45	25.908 1	278.871	77.724 2	92.956 9	136.795	52.816 4
86	2 184.40	3.385 82	26.212 9	282.152	78.638 6	94.050 6	138.404	53.437 8
87	2 209.80	3.425 19	26.517 7	285.433	79.553 0	95.144 2	140.013	54.059 2
88	2 235.20	3.464 56	26.822 5	288.713	80.467 4	96.237 8	141.623	54.680 6
89	2 260.60	3.503 93	27.127 3	291.994	81.381 8	97.331 4	143.232	55.301 9
90	2 286.00	3.543 30	27.432 1	295.275	82.296 2	98.425 0	144.841	55.923 3
91	2 311.40	3.582 67	27.736 9	298.556	83.210 6	99.518 6	146.451	56.544 7
92	2 336.80	3.622 04	28.041 7	301.837	84.125 0	100.612	148.060	57.160 0
93	2 362.20	3.661 41	28.346 5	305.118	85.039 4	101.706	149.669	57.787 4
94	2 387.60	3.700 78	28.651 3	308.398	85.953 8	102.799	151.279	58.408 8
95	2 413.00	3.740 15	28.956 1	311.679	86.868 2	103.893	152.888	59.030 1
96	2 438.40	3.779 52	29.260 9	314.960	87.782 6	104.987	154.497	59.651 5
97	2 463.80	3.818 89	29.565 7	318.241	88.697 0	106.080	156.107	60.272 9
98	2 489.20	3.858 26	29.870 5	321.522	89.611 4	107.174	157.716	60.894 3
99	2 514.60	3.897 63	30.175 3	324.803	90.525 8	108.268	159.325	61.515 6
100	2 540.01	3.937 00	30.480 1	328.083	91.440 2	109.361	160.935	62.137 0

From "Ready Reference Tables," courtesy Carl Hering.

TEMPERATURE CONVERSIONS

Albert Sauveur type of table. Look up reading in middle column; if in degrees Centigrade, read Fahrenheit equivalent in right hand column; if in degrees Fahrenheit, read Centigrade equivalent in left hand column.

−459.4 to 0			*0 to 100*						*100 to 1000*					
C		*F*	*C*		*F*	*C*		*F*	*C*		*F*	*C*		*F*
−273	*−459.4*		−17.8	*0*	32	10.0	*50*	122.0	38	*100*	212	260	*500*	932
−268	*−450*		−17.2	*1*	33.8	10.6	*51*	123.8	43	*110*	230	266	*510*	950
−262	*−440*		−16.7	*2*	35.6	11.1	*52*	125.6	49	*120*	248	271	*520*	968
−257	*−430*		−16.1	*3*	37.4	11.7	*53*	127.4	54	*130*	266	277	*530*	986
−251	*−420*		−15.6	*4*	39.2	12.2	*54*	129.2	60	*140*	284	282	*540*	1004
−246	*−410*		−15.0	*5*	41.0	12.8	*55*	131.0	66	*150*	302	288	*550*	1022
−240	*−400*		−14.4	*6*	42.8	13.3	*56*	132.8	71	*160*	320	293	*560*	1040
−234	*−390*		−13.9	*7*	44.6	13.9	*57*	134.6	77	*170*	338	299	*570*	1058
−229	*−380*		−13.3	*8*	46.4	14.4	*58*	136.4	82	*180*	356	304	*580*	1076
−223	*−370*		−12.8	*9*	48.2	15.0	*59*	138.2	88	*190*	374	310	*590*	1094
−218	*−360*		−12.2	*10*	50.0	15.6	*60*	140.0	93	*200*	392	316	*600*	1112
−212	*−350*		−11.7	*11*	51.8	16.1	*61*	141.8	99	*210*	410	321	*610*	1130
−207	*−340*		−11.1	*12*	53.6	16.7	*62*	143.6	100	*212*	413.6	327	*620*	1148
−201	*−330*		−10.6	*13*	55.4	17.2	*63*	145.4	104	*220*	428	332	*630*	1166
−196	*−320*		−10.0	*14*	57.2	17.8	*64*	147.2	110	*230*	446	338	*640*	1184
−190	*−310*		− 9.4	*15*	59.0	18.3	*65*	149.0	116	*240*	464	343	*650*	1202
−184	*−300*		− 8.9	*16*	60.8	18.9	*66*	150.8	121	*250*	482	349	*660*	1220
−179	*−290*		− 8.3	*17*	62.6	19.4	*67*	152.6	127	*260*	500	354	*670*	1238
−173	*−280*		− 7.8	*18*	64.4	20.0	*68*	154.4	132	*270*	518	360	*680*	1256
−169	*−273*	−459.4	− 7.2	*19*	66.2	20.6	*69*	156.2	138	*280*	536	366	*690*	1274
−168	*−270*	−454	− 6.7	*20*	68.0	21.1	*70*	158.0	143	*290*	554	371	*700*	1292
−162	*−260*	−436	− 6.1	*21*	69.8	21.7	*71*	159.8	149	*300*	572	377	*710*	1310
−157	*−250*	−418	− 5.6	*22*	71.6	22.2	*72*	161.6	154	*310*	590	382	*720*	1328
−151	*−240*	−400	− 5.0	*23*	73.4	22.8	*73*	163.4	160	*320*	608	388	*730*	1346
−146	*−230*	−382	− 4.4	*24*	75.2	23.3	*74*	165.2	166	*330*	626	393	*740*	1364
−140	*−220*	−364	− 3.9	*25*	77.0	23.9	*75*	167.0	171	*340*	644	399	*750*	1382
−134	*−210*	−346	− 3.3	*26*	78.8	24.4	*76*	168.8	177	*350*	662	404	*760*	1400
−129	*−200*	−328	− 2.8	*27*	80.6	25.0	*77*	170.6	182	*360*	680	410	*770*	1418
−123	*−190*	−310	− 2.2	*28*	82.4	25.6	*78*	172.4	188	*370*	698	416	*780*	1436
−118	*−180*	−292	− 1.7	*29*	84.2	26.1	*79*	174.2	193	*380*	716	421	*790*	1454
−112	*−170*	−274	− 1.1	*30*	86.0	26.7	*80*	176.0	199	*390*	734	427	*800*	1472
−107	*−160*	−256	− 0.6	*31*	87.8	27.2	*81*	177.8	204	*400*	752	432	*810*	1490
−101	*−150*	−238	0.0	*32*	89.6	27.8	*82*	179.6	210	*410*	770	438	*820*	1508
− 96	*−140*	−220	0.6	*33*	91.4	28.3	*83*	181.4	216	*420*	788	443	*830*	1526
− 90	*−130*	−202	1.1	*34*	93.2	28.9	*84*	183.2	221	*430*	806	449	*840*	1544
− 84	*−120*	−184	1.7	*35*	95.0	29.4	*85*	185.0	227	*440*	824	454	*850*	1562
− 79	*−110*	−166	2.2	*36*	96.8	30.0	*86*	186.8	232	*450*	842	460	*860*	1580
− 73	*−100*	−148	2.8	*37*	98.6	30.6	*87*	188.6	238	*460*	860	466	*870*	1598
− 68	*− 90*	−130	3.3	*38*	100.4	31.1	*88*	190.4	243	*470*	878	471	*880*	1616
− 62	*− 80*	−112	3.9	*39*	102.2	31.7	*89*	192.2	249	*480*	896	477	*890*	1634
− 57	*− 70*	− 94	4.4	*40*	104.0	32.2	*90*	194.0	254	*490*	914	482	*900*	1652
− 51	*− 60*	− 76	5.0	*41*	105.8	32.8	*91*	195.8				488	*910*	1670
− 46	*− 50*	− 58	5.6	*42*	107.6	33.3	*92*	197.6				493	*920*	1688
− 40	*− 40*	− 40	6.1	*43*	109.4	33.9	*93*	199.4				499	*930*	1706
− 34	*− 30*	− 22	6.7	*44*	111.2	34.4	*94*	201.2				504	*940*	1724
− 29	*− 20*	− 4	7.2	*45*	113.0	35.0	*95*	203.0				510	*950*	1742
− 23	*− 10*	14	7.8	*46*	114.8	35.6	*96*	204.8				516	*960*	1760
− 17.8	*0*	32	8.3	*47*	116.6	36.1	*97*	206.6				521	*970*	1778
			8.9	*48*	118.4	36.7	*98*	208.4				527	*980*	1796
			9.4	*49*	120.2	37.2	*99*	210.2				532	*990*	1814
						37.8	*100*	212.0				538	*1000*	1832

TEMPERATURE CONVERSIONS —*Continued*

1000 to 2000						*2000 to 3000*					
C		F	C		F	C		F	C		F
538	*1000*	1832	816	*1500*	2732	1093	*2000*	3632	1371	*2500*	4532
543	*1010*	1850	821	*1510*	2750	1099	*2010*	3650	1377	*2510*	4550
549	*1020*	1868	827	*1520*	2768	1104	*2020*	3668	1382	*2520*	4568
554	*1030*	1886	832	*1530*	2786	1110	*2030*	3686	1388	*2530*	4586
560	*1040*	1904	838	*1540*	2804	1116	*2040*	3704	1393	*2540*	4604
566	*1050*	1922	843	*1550*	2822	1121	*2050*	3722	1399	*2550*	4622
571	*1060*	1940	849	*1560*	2840	1127	*2060*	3740	1404	*2560*	4640
577	*1070*	1958	854	*1570*	2858	1132	*2070*	3758	1410	*2570*	4658
582	*1080*	1976	860	*1580*	2876	1138	*2080*	3776	1416	*2580*	4676
588	*1090*	1994	866	*1590*	2894	1143	*2090*	3794	1421	*2590*	4694
593	*1100*	2012	871	*1600*	2912	1149	*2100*	3812	1427	*2600*	4712
599	*1110*	2030	877	*1610*	2930	1154	*2110*	3830	1432	*2610*	4730
604	*1120*	2048	882	*1620*	2948	1160	*2120*	3848	1438	*2620*	4748
610	*1130*	2066	888	*1630*	2966	1166	*2130*	3866	1443	*2630*	4766
616	*1140*	2084	893	*1640*	2984	1171	*2140*	3884	1449	*2640*	4784
621	*1150*	2102	899	*1650*	3002	1177	*2150*	3902	1454	*2650*	4802
627	*1160*	2120	904	*1660*	3020	1182	*2160*	3920	1460	*2660*	4820
632	*1170*	2138	910	*1670*	3038	1188	*2170*	3938	1466	*2670*	4838
638	*1180*	2156	916	*1680*	3056	1193	*2180*	3956	1471	*2680*	4856
643	*1190*	2174	921	*1690*	3074	1199	*2190*	3974	1477	*2690*	4874
649	*1200*	2192	927	*1700*	3092	1204	*2200*	3992	1482	*2700*	4892
654	*1210*	2210	932	*1710*	3110	1210	*2210*	4010	1488	*2710*	4910
660	*1220*	2228	938	*1720*	3128	1216	*2220*	4028	1493	*2720*	4928
666	*1230*	2246	943	*1730*	3146	1221	*2230*	4046	1499	*2730*	4946
671	*1240*	2264	949	*1740*	3164	1227	*2240*	4064	1504	*2740*	4964
677	*1250*	2282	954	*1750*	3182	1232	*2250*	4082	1510	*2750*	4982
682	*1260*	2300	960	*1760*	3200	1238	*2260*	4100	1516	*2760*	5000
688	*1270*	2318	966	*1770*	3218	1243	*2270*	4118	1521	*2770*	5018
693	*1280*	2336	971	*1780*	3236	1249	*2280*	4136	1527	*2780*	5036
699	*1290*	2354	977	*1790*	3254	1254	*2290*	4154	1532	*2790*	5054
704	*1300*	2372	982	*1800*	3272	1260	*2300*	4172	1538	*2800*	5072
710	*1310*	2390	988	*1810*	3290	1266	*2310*	4190	1543	*2810*	5090
716	*1320*	2408	993	*1820*	3308	1271	*2320*	4208	1549	*2820*	5108
721	*1330*	2426	999	*1830*	3326	1277	*2330*	4226	1554	*2830*	5126
727	*1340*	2444	1004	*1840*	3344	1282	*2340*	4244	1560	*2840*	5144
732	*1350*	2462	1010	*1850*	3362	1288	*2350*	4262	1566	*2850*	5162
738	*1360*	2480	1016	*1860*	3380	1293	*2360*	4280	1571	*2860*	5180
743	*1370*	2498	1021	*1870*	3398	1299	*2370*	4298	1577	*2870*	5198
749	*1380*	2516	1027	*1880*	3416	1304	*2380*	4316	1582	*2880*	5216
754	*1390*	2534	1032	*1890*	3434	1310	*2390*	4334	1588	*2890*	5234
760	*1400*	2552	1038	*1900*	3452	1316	*2400*	4352	1593	*2900*	5252
766	*1410*	2570	1043	*1910*	3470	1321	*2410*	4370	1599	*2910*	5270
771	*1420*	2588	1049	*1920*	3488	1327	*2420*	4388	1604	*2920*	5288
777	*1430*	2606	1054	*1930*	3506	1332	*2430*	4406	1610	*2930*	5306
782	*1440*	2624	1060	*1940*	3524	1338	*2440*	4424	1616	*2940*	5324
788	*1450*	2642	1066	*1950*	3542	1343	*2450*	4442	1621	*2950*	5342
793	*1460*	2660	1071	*1960*	3560	1349	*2460*	4460	1627	*2960*	5360
799	*1470*	2678	1077	*1970*	3578	1354	*2470*	4478	1632	*2970*	5378
804	*1480*	2696	1082	*1980*	3596	1360	*2480*	4496	1638	*2980*	5396
810	*1490*	2714	1088	*1990*	3614	1366	*2490*	4514	1643	*2990*	5414
			1093	*2000*	3632				1649	*3000*	5432

HARDNESS CONVERSIONS FOR STEEL

From A.S.T.M. Standards (A.S.T.M. Designation: E-140-58)

	Brinell Hardness Number			*Rockwell Hardness Number*			*Rockwell Superficial Hardness Number*			
Diamond Pyramid Hardness Number	*10-mm Standard Ball, 3000-kg Load*	*10-mm Hultgren Ball, 3000-kg Load*	*10-mm Carbide Ball, 3000-kg Load*	*C Scale, 150-kg Load, Brale Penetrator*	*A Scale, 60-kg Load, Brale Penetrator*	*D Scale, 100-kg Load, Brale Penetrator*	*15-N Scale, 15-kg Load, Superficial Brale Penetrator*	*30-N Scale, 30-kg Load, Superficial Brale Penetrator*	*45-N Scale, 45-kg Load, Superficial Brale Penetrator*	*Diamond Pyramid Hardness Number*
940	*	---	---	68.0	85.6	76.9	93.2	84.4	75.4	940
920	*	---	---	67.5	85.3	76.5	93.0	84.0	74.8	920
900	*	---	---	67.0	85.0	76.1	92.9	83.6	74.2	900
880	*	---	---	66.4	84.7	75.7	92.7	83.1	73.6	880
860	*	---	---	65.9	84.4	75.3	92.5	82.7	73.1	860
840	*	---	745	65.3	84.1	74.8	92.3	82.2	72.2	840
820	*	---	733	64.7	83.8	74.3	92.1	81.7	71.8	820
800	*	---	722	64.0	83.4	73.8	91.8	81.1	71.0	800
780	*	---	710	63.3	83.0	73.3	91.5	80.4	70.2	780
760	*	---	698	62.5	82.6	72.6	91.2	79.7	69.4	760
740	*	---	684	61.8	82.2	72.1	91.0	79.1	68.6	740
720	*	---	670	61.0	81.8	71.5	90.7	78.4	67.7	720
700	*	615	656	60.1	81.3	70.8	90.3	77.6	66.7	700
690	*	610	647	59.7	81.1	70.5	90.1	77.2	66.2	690
680	*	603	638	59.2	80.8	70.1	89.8	76.8	65.7	680
670	*	597	630	58.8	80.6	69.8	89.7	76.4	65.3	670
660	*	590	620	58.3	80.3	69.4	89.5	75.9	64.7	660
650	*	585	611	57.8	80.0	69.0	89.2	75.5	64.1	650
640	*	578	601	57.3	79.8	68.7	89.0	75.1	63.5	640
630	*	571	591	56.8	79.5	68.3	88.8	74.6	63.0	630
620	*	564	582	56.3	79.2	67.9	88.5	74.2	62.4	620
610	*	557	573	55.7	78.9	67.5	88.2	73.6	61.7	610
600	*	550	564	55.2	78.6	67.0	88.0	73.2	61.2	600
590	*	542	554	54.7	78.4	66.7	87.8	72.7	60.5	590
580	*	535	545	54.1	78.0	66.2	87.5	72.1	59.9	580
570	*	527	535	53.6	77.8	65.8	87.2	71.7	59.3	570
560	*	519	525	53.0	77.4	65.4	86.9	71.2	58.6	560
550	505	512	517	52.3	77.0	64.8	86.6	70.5	57.8	550
540	496	503	507	51.7	76.7	64.4	86.3	70.0	57.0	540
530	488	495	497	51.1	76.4	63.9	86.0	69.5	56.2	530
520	480	487	488	50.5	76.1	63.5	85.7	69.0	55.6	520
510	473	479	479	49.8	75.7	62.9	85.4	68.3	54.7	510
500	465	471	471	49.1	75.3	62.2	85.0	67.7	53.9	500
490	456	460	460	48.4	74.9	61.6	84.7	67.1	53.1	490
480	448	452	452	47.7	74.5	61.3	84.3	66.4	52.2	480
470	441	442	442	46.9	74.1	60.7	83.9	65.7	51.3	470
460	433	433	433	46.1	73.6	60.1	83.6	64.9	50.4	460
450	425	425	425	45.3	73.3	59.4	83.2	64.3	49.4	450
440	415	415	415	44.5	72.8	58.8	82.8	63.5	48.4	440
430	405	405	405	43.6	72.3	58.2	82.3	62.7	47.4	430
420	397	397	397	42.7	71.8	57.5	81.8	61.9	46.4	420
410	388	388	388	41.8	71.4	56.8	81.4	61.1	45.3	410
400	379	379	379	40.8	70.8	56.0	80.0	60.2	44.1	400
390	369	369	369	39.8	70.3	55.2	80.3	59.3	42.9	390
380	360	360	360	38.8	69.8	54.4	79.8	58.4	41.7	380
370	350	350	350	37.7	69.2	53.6	79.2	57.4	40.4	370
360	341	341	341	36.6	68.7	52.8	78.6	56.4	39.1	360
350	331	331	331	35.5	68.1	51.9	78.0	55.4	37.8	350
340	322	322	322	34.4	67.6	51.1	77.4	54.4	36.5	340
330	313	313	313	33.3	67.0	50.2	76.8	53.6	35.2	330
320	303	303	303	32.2	66.4	49.4	76.2	52.3	33.9	320
310	294	294	294	31.0	65.8	48.4	75.6	51.3	32.5	310
300	284	284	284	29.8	65.2	47.5	74.9	50.2	31.1	300
295	280	280	280	29.2	64.8	47.1	74.6	49.7	30.4	295
290	275	275	275	28.5	64.5	46.5	74.2	49.0	29.5	290
285	270	270	270	27.8	64.2	46.0	73.8	48.4	28.7	285
280	265	265	265	27.1	63.8	45.3	73.4	47.8	27.9	280
275	261	261	261	26.4	63.5	44.9	73.0	47.2	27.1	275
270	256	256	256	25.6	63.1	44.3	72.6	46.4	26.2	270
265	252	252	252	24.8	62.7	43.7	72.1	45.7	25.2	265
260	247	247	247	24.0	62.4	43.1	71.6	45.0	24.3	260
255	243	243	243	23.1	62.0	42.2	71.1	44.2	23.2	255
250	238	238	238	22.2	61.6	41.7	70.6	43.4	22.2	250
245	233	233	233	21.3	61.2	41.1	70.1	42.5	21.1	245
240	228	228	228	20.3	60.7	40.3	69.6	41.7	19.9	240

* No Brinell hardness values are given above 500 Brinell hardness number for the 10-mm standard steel ball in conformance with limitations established by the Standard Method of Test for Brinell Hardness of Metallic Materials (A.S.T.M. Designation: E 10).*
Courtesy A.S.T.M.

HARDNESS CONVERSIONS FOR STEEL—*Continued*

From A.S.T.M. Standards (A.S.T.M. Designation: E-140-58)

Rockwell C Hardness Number	Diamond Pyramid Hardness Number	Brinell Hardness Number			Rockwell Hardness Number		Rockwell Superficial Hardness Number			Rockwell C Hardness Number
		10-mm Standard Ball, 3000-kg Load	10-mm Hultgren Ball, 3000-kg Load	10-mm Carbide Ball, 3000-kg Load	A Scale, 60-kg Load, Brale Penetrator	D Scale, 100-kg Load, Brale Penetrator	15-N Scale, 15-kg Load, Superficial Brale Penetrator	30-N Scale, 30-kg Load, Superficial Brale Penetrator	45-N Scale, 45-kg Load, Superficial Brale Penetrator	
68	940	*	---	---	85.6	76.9	93.2	84.4	75.4	68
67	900	*	---	---	85.0	76.1	92.9	83.6	74.2	67
66	865	*	---	---	84.5	75.4	92.5	82.8	73.3	66
65	832	*	---	739	83.9	74.5	92.2	81.9	72.0	65
64	800	*	---	722	83.4	73.8	91.8	81.1	71.0	64
63	772	*	---	705	82.8	73.0	91.4	80.1	69.9	63
62	746	*	---	688	82.3	72.2	91.1	79.3	68.8	62
61	720	*	---	670	81.8	71.5	90.7	78.4	67.7	61
60	697	*	613	654	81.2	70.7	90.2	77.5	66.6	60
59	674	*	599	634	80.7	69.9	89.8	76.6	65.5	59
58	653	*	587	615	80.1	69.2	89.3	75.7	64.3	58
57	633	*	575	595	79.6	68.5	88.9	74.8	63.2	57
56	613	*	561	577	79.0	67.7	88.3	73.9	62.0	56
55	595	*	546	560	78.5	66.9	87.9	73.0	60.9	55
54	577	*	534	543	78.0	66.1	87.4	72.0	59.8	54
53	560	*	519	525	77.4	65.4	86.9	71.2	58.6	53
52	544	500	508	512	76.8	64.6	86.4	70.2	57.4	52
51	528	487	494	496	76.3	63.8	85.9	69.4	56.1	51
50	513	475	481	481	75.9	63.1	85.5	68.5	55.0	50
49	498	464	469	469	75.2	62.1	85.0	67.6	53.8	49
48	484	451	455	455	74.7	61.4	84.5	66.7	52.5	48
47	471	442	443	443	74.1	60.8	83.9	65.8	51.4	47
46	458	432	432	432	73.6	60.0	83.5	64.8	50.3	46
45	446	421	421	421	73.1	59.2	83.0	64.0	49.0	45
44	434	409	409	409	72.5	58.5	82.5	63.1	47.8	44
43	423	400	400	400	72.0	57.7	82.0	62.2	46.7	43
42	412	390	390	390	71.5	56.9	81.5	61.3	45.5	42
41	402	381	381	381	70.9	56.2	80.9	60.4	44.3	41
40	392	371	371	371	70.4	55.4	80.4	59.5	43.1	40
39	382	362	362	362	69.9	54.6	79.9	58.6	41.9	39
38	372	353	353	353	69.4	53.8	79.4	57.7	40.8	38
37	363	344	344	344	68.9	53.1	78.8	56.8	39.6	37
36	354	336	336	336	68.4	52.3	78.3	55.9	38.4	36
35	345	327	327	327	67.9	51.5	77.7	55.0	37.2	35
34	336	319	319	319	67.4	50.8	77.2	54.2	36.1	34
33	327	311	311	311	66.8	50.0	76.6	53.3	34.9	33
32	318	301	301	301	66.3	49.2	76.1	52.1	33.7	32
31	310	294	294	294	65.8	48.4	75.6	51.3	32.5	31
30	302	286	286	286	65.3	47.7	75.0	50.4	31.3	30
29	294	279	279	279	64.7	47.0	74.5	49.5	30.1	29
28	286	271	271	271	64.3	46.1	73.9	48.6	28.9	28
27	279	264	264	264	63.8	45.2	73.3	47.7	27.8	27
26	272	258	258	258	63.3	44.6	72.8	46.8	26.7	26
25	266	253	253	253	62.8	43.8	72.2	45.9	25.5	25
24	260	247	247	247	62.4	43.1	71.6	45.0	24.3	24
23	254	243	243	243	62.0	42.1	71.0	44.0	23.1	23
22	248	237	237	237	61.5	41.6	70.5	43.2	22.0	22
21	243	231	231	231	61.0	40.9	69.9	42.3	20.7	21
20	238	226	226	226	60.5	40.1	69.4	41.5	19.6	20

* No Brinell hardness values are given above 500 Brinell hardness number for the 10-mm. standard steel ball in conformance with limitations established by the Standard Method of Test or Brinell Hardness of Metallic Materials (A.S.T.M. Designation: E 10).[4] Courtesy A.S.T.M.

HARDNESS CONVERSIONS FOR STEEL—*Continued*

From A.S.T.M. Standards (A.S.T.M. Designation: E-140-58)

	Brinell Hardness Number				Rockwell Hardness Number			Rockwell Superficial Hardness Number			
Brinell Indentation Diameter, mm	*10-mm Standard Ball, 3000-kg Load*	*10-mm Hultgren Ball, 3000-kg Load*	*10-mm Carbide Ball, 3000-kg Load*	*Diamond Pyramid Hardness Number*	*C Scale, 150-kg Load, Brale Penetrator*	*A Scale, 60-kg Load, Brale Penetrator*	*D Scale, 100-kg Load, Brale Penetrator*	*15-N Scale, 15-kg Load, Superficial Brale Penetrator*	*30-N Scale, 30-kg Load, Superficial Brale Penetrator*	*45-N Scale, 45-kg Load, Superficial Brale Penetrator*	*Brinell Indentation Diameter, mm*
2.35	*	---	682	737	61.7	82.2	72.0	91.0	79.0	68.5	2.35
2.40	*	---	653	697	60.0	81.2	70.7	90.2	77.5	66.5	2.40
2.45	*	---	627	667	58.7	80.5	69.7	89.6	76.3	65.1	2.45
	*	---	---	---	---	---	---	---	---	---	
2.50	---	601	---	677	59.1	80.7	70.0	89.8	76.8	65.7	2.50
	---	---	601	640	57.3	79.8	68.7	89.0	75.1	63.5	
	*	---	---	---	---	---	---	---	---	---	
2.55	---	578	---	640	57.3	79.8	68.7	89.0	75.1	63.5	2.55
	---	---	578	615	56.0	79.1	67.7	88.4	73.9	62.1	
	*	---	---	---	---	---	---	---	---	---	
2.60	---	555	---	607	55.6	78.8	67.4	88.1	73.5	61.6	2.60
	---	---	555	591	54.7	78.4	66.7	87.8	72.7	60.6	
	*	---	---	---	---	---	---	---	---	---	
2.65	---	534	---	579	54.0	78.0	66.1	87.5	72.0	59.8	2.65
	---	---	534	569	53.5	77.8	65.8	87.2	71.6	59.2	
	*	---	---	---	---	---	---	---	---	---	
2.70	---	514	---	553	52.5	77.1	65.0	86.7	70.7	58.0	2.70
	---	---	514	547	52.1	76.9	64.7	86.5	70.3	57.6	
	495	---	---	539	51.6	76.7	64.3	86.3	69.9	56.9	
2.75	---	495	---	530	51.1	76.4	63.9	86.0	69.5	56.2	2.75
	---	---	495	528	51.0	76.3	63.8	85.9	69.4	56.1	
	477	---	---	516	50.3	75.9	63.2	85.6	68.7	55.2	
2.80	---	477	---	508	49.6	75.6	62.7	85.3	68.2	54.5	2.80
	---	---	477	508	49.6	75.6	62.7	85.3	68.2	54.5	
	461	---	---	495	48.8	75.1	61.9	84.9	67.4	53.5	
2.85	---	461	---	491	48.5	74.9	61.7	84.7	67.2	53.2	2.85
	---	---	461	491	48.5	74.9	61.7	84.7	67.2	53.2	
	444	---	---	474	47.2	74.3	61.0	84.1	66.0	51.7	
2.90	---	444	---	472	47.1	74.2	60.8	84.0	65.8	51.5	2.90
	---	---	444	472	47.1	74.2	60.8	84.0	65.8	51.5	
2.95	429	429	429	455	45.7	73.4	59.7	83.4	64.6	49.9	2.95
3.00	415	415	415	440	44.5	72.8	58.8	82.8	63.5	48.4	3.00
3.05	401	401	401	425	43.1	72.0	57.8	82.0	62.3	46.9	3.05
3.10	388	388	388	410	41.8	71.4	56.8	81.4	61.1	45.3	3.10
3.15	375	375	375	396	40.4	70.6	55.7	80.6	59.9	43.6	3.15
3.20	363	363	363	383	39.1	70.0	54.6	80.0	58.7	42.0	3.20
3.25	352	352	352	372	37.9	69.3	53.8	79.3	57.6	40.5	3.25
3.30	341	341	341	360	36.6	68.7	52.8	78.6	56.4	39.1	3.30
3.35	331	331	331	350	35.5	68.1	51.9	78.0	55.4	37.8	3.35
3.40	321	321	321	339	34.3	67.5	51.0	77.3	54.3	36.4	3.40
3.45	311	311	311	328	33.1	66.9	50.0	76.7	53.3	34.4	3.45
3.50	302	302	302	319	32.1	66.3	49.3	76.1	52.2	33.8	3.50
3.55	293	293	293	309	30.9	65.7	48.3	75.5	51.2	32.4	3.55
3.60	285	285	285	301	29.9	65.3	47.6	75.0	50.3	31.2	3.60
3.65	277	277	277	292	28.8	64.6	46.7	74.4	49.2	29.9	3.65
3.70	269	269	269	284	27.6	64.1	45.9	73.7	48.1	28.5	3.70
3.75	262	262	262	276	26.6	63.6	45.0	73.1	47.3	27.3	3.75
3.80	255	255	255	269	25.4	63.0	44.2	72.5	46.2	26.0	3.80
3.85	248	248	248	261	24.2	62.5	43.2	71.7	45.1	24.5	3.85
3.90	241	241	241	253	22.8	61.8	42.0	70.9	43.9	22.8	3.90
3.95	235	235	235	247	21.7	61.4	41.4	70.3	42.9	21.5	3.95
4.00	229	229	229	241	20.5	60.8	40.5	69.7	41.9	20.1	4.00

* No Brinell hardness values are given above 500 Brinell hardness number for the 10-mm. standard steel ball in comformance with limitations established by the Standard Method of Test for Brinell Hardness of Metallic Materials (A.S.T.M. Designation: E 10.)
Courtesy A.S.T.M.

HARDNESS CONVERSIONS FOR STEEL—*Continued*

From A.S.M. Handbook (1939 Edition) (Brinnell—Rockwell B—Scleroscope)

Brinell Hardness Number	*Rockwell B 100 Kg. Load 1/16 In. Diam. Ball*	*Shore Scleroscope Number*	*Brinell Hardness Number*	*Rockwell B 100 Kg. Load 1/16 In. Diam. Ball*	*Shore Scleroscope Number*
---	---	95	255	102	37
---	---	91	248	102	36
---	---	87	241	100	35
---	---	84	235	99	34
---	---	81	229	98	33
578	---	78	223	97	32
555	---	75	217	96	31
534	---	72	212	96	31
514	---	70	207	95	30
495	---	67	202	94	30
477	---	65	197	93	29
461	---	63	192	92	28
444	---	61	187	91	28
429	---	59	183	90	27
415	---	57	179	89	27
401	---	55	174	88	26
388	---	54	170	87	26
375	---	52	166	86	25
363	---	51	163	85	25
352	---	49	159	84	24
341	---	48	156	83	24
331	---	46	153	82	23
321	---	45	149	81	23
311	---	44	146	80	22
302	---	43	143	79	22
293	---	42	140	78	21
285	---	40	137	77	21
277	104	39	134	76	21
269	104	38	131	74	20
262	103	37	128	73	20

CIRCUMFERENCES AND AREAS OF CIRCLES

Of One Inch				*Of Inches or Feet*					
Fract.	*Dec.*	*Circ.*	*Area*	*Dia.*	*Circ.*	*Area*	*Dia.*	*Circ.*	*Area*
1/64	.015625	.04909	.00019	1	3.1416	.7854	64	201.06	3216.99
1/32	.03125	.09818	.00077	2	6.2832	3.1416	65	204.20	3318.31
3/64	.046875	.14726	.00173	3	9.4248-	7.0686	66	207.34	3421.19
1/16	.0625	.19635	.00307	4	12.5664	12.5664	67	210.49	3525.65
5/64	.078125	.24545	.00479	5	15.7080	19.635	68	213.63	3631.68
3/32	.09375	.29452	.00690	6	18.850	28.274	69	216.77	3739.28
7/64	.109375	.34363	.00939	7	21.991	38.485	70	219.91	3848.45
1/8	.125	.39270	.01227	8	25.133	50.266	71	223.05	3959.19
9/64	.140625	.44181	.01553	9	28.274	63.617	72	226.19	4071.50
5/32	.15625	.49087	.01917	10	31.416	78.540	73	229.34	4185.39
11/64	.171875	.53999	.02320	11	34.558	95.033	74	232.48	4300.84
3/16	.1875	.58905	.02761	12	37.699	113.1	75	235.62	4417.86
13/64	.203125	.63817	.03241	13	40.841	132.73	76	238.76	4536.46
7/32	.21875	.68722	.03758	14	43.982	153.94	77	241.90	4656.63
15/64	.234375	.73635	.04314	15	47.124	176.71	78	245.04	4778.36
1/4	.25	.78540	.04909	16	50.265	201.06	79	248.19	4901.67
17/64	.265625	.83453	.05542	17	53.407	226.98	80	251.33	5026.55
9/32	.28125	.88357	.06213	18	56.549	254.47	81	254.47	5153.
19/64	.296875	.93271	.06922	19	59.690	283.53	82	257.61	5281.02
5/16	.3125	.98175	.07670	20	62.832	314.16	83	260.75	5410.61
21/64	.328125	1.0309	.08456	21	65.973	346.36	84	263.89	5541.77
11/32	.34375	1.0799	.09281	22	69.115	380.13	85	267.04	5674.50
23/64	.359375	1.1291	.10144	23	72.257	415.48	86	270.18	5808.80
3/8	.375	1.1781	.11045	24	75.398	452.39	87	273.32	5944.68
25/64	.390625	1.2273	.11984	25	79.540	490.87	88	276.46	6082.12
13/32	.40625	1.2763	.12962	26	81.681	530.93	89	279.60	6221.14
27/64	.421875	1.3254	.13979	27	84.823	572.56	90	282.74	6361.73
7/16	.4375	1.3744	.15033	28	87.965	615.75	91	285.88	6503.88
29/64	.453125	1.4236	.16126	29	91.106	660.52	92	289.03	6647.61
15/32	.46875	1.4726	.17257	30	94.248	706.86	93	292.17	6792.91
31/64	.484375	1.5218	.18427	31	97.389	754.77	94	295.31	6939.78
1/2	.5	1.5708	.19635	32	100.53	804.25	95	298.45	7088.22
33/64	.515625	1.6199	.20880	33	103.67	855.30	96	301.59	7238.23
17/32	.53125	1.6690	.22166	34	106.81	907.92	97	304.73	7339.81
35/64	.546875	1.7181	.23489	35	109.96	962.11	98	307.88	7542.96
9/16	.5625	1.7671	.24850	36	113.10	1017.88	99	311.02	7697.69
37/64	.578125	1.8163	.26248	37	116.24	1075.21	100	314.16	7953.98
19/32	.59375	1.8653	.27688	38	119.38	1134.11	101	317.30	8011.85
39/64	.609375	1.9145	.29164	39	122.52	1194.59	102	320.44	8171.28
5/8	.625	1.9635	.30680	40	125.66	1256.64	103	323.58	8332.29
41/64	.640625	2.0127	.32232	41	128.81	1320.25	104	326.73	8494.87
21/32	.65625	2.0617	.33824	42	131.95	1385.44	105	329.87	8659.01
43/64	.671875	2.1108	.35453	43	135.09	1452.20	106	333.01	8824.73
11/16	.6875	2.1598	.37122	44	138.23	1520.53	107	336.15	8992.02
45/64	.703125	2.2090	.38828	45	141.37	1590.43	108	339.29	9160.88
23/32	.71875	2.2580	.40574	46	144.51	1661.90	109	342.43	9331.32
47/64	.734375	2.3072	.42356	47	147.65	1734.94	110	345.58	9503.32
3/4	.75	2.3562	.44179	48	150.80	1809.56	111	348.72	9676.89
49/64	.765625	2.4054	.45253	49	153.94	1885.74	112	351.86	9852.03
25/32	.78125	2.4544	.47937	50	157.08	1963.50	113	355.	10028.75
51/64	.796875	2.5036	.49872	51	160.22	2042.82	114	358.14	10207.03
13/16	.8125	2.5525	.51849	52	163.36	2123.72	115	361.28	10386.89
53/64	.828125	2.6017	.53862	53	166.50	2206.18	116	364.42	10568.32
27/32	.84375	2.6507	.55914	54	169.65	2290.22	117	367.57	10751.32
55/64	.859375	2.6999	.58003	55	172.79	2375.83	118	370.71	10935.88
7/8	.875	2.7489	.60132	56	175.93	2463.01	119	373.85	11122.02
57/64	.890625	2.7981	.62298	57	179.07	2551.76	120	377.99	11309.73
29/32	.90625	2.8471	.64504	58	182.21	2642.08	121	380.13	11499.01
59/64	.921875	2.8963	.66746	59	185.35	2733.97	122	383.27	11689.87
15/16	.9375	2.9452	.69029	60	188.50	2827.43	123	386.42	11882.29
61/64	.953125	2.9945	.71349	61	191.64	2922.47	124	389.56	12076.28
31/32	.96875	3.0434	.73708	62	194.78	3019.07	125	392.70	12271.85
63/64	.984375	3.0928	.76097	63	197.20	3117.25	126	395.84	12468.98

FRACTIONS OF AN INCH AND DECIMAL EQUIVALENTS

1/64	.015625	33/64	.51562
1/32	.03125	17/32	.53125
3/64	.046875	35/64	.54687
1/16	.0625	9/16	.5625
5/64	.078125	37/64	.578125
3/32	.09375	19/32	.59375
7/64	.109375	39/64	.609375
1/8	.125	5/8	.625
9/64	.140625	41/64	.640625
5/32	.15625	21/32	.65625
11/64	.171875	43/64	.671875
3/16	.1875	11/16	.6875
13/64	.203125	45/64	.703125
7/32	.21875	23/32	.71875
15/64	.234375	47/64	.734375
1/4	.250	3/4	.750
17/64	.265625	49/64	.765625
9/32	.28125	25/32	.78125
19/64	.296875	51/64	.796875
5/16	.3125	13/16	.8125
21/64	.328125	53/64	.828125
11/32	.34375	27/32	.84375
23/64	.359375	55/64	.859375
3/8	.375	7/8	.875
25/64	.390625	57/64	.890625
13/32	.40625	29/32	.90625
27/64	.421875	59/64	.921875
7/16	.4375	15/16	.9375
29/64	.453125	61/64	.953125
15/32	.46875	31/32	.96875
31/64	.484375	63/64	.984375
1/2	.500	1	1.0000

DISTRICT SERVICE CENTERS

Call Crucible at Service Center Near You for Prompt Service

		ZIP CODE	AREA CODE	
Atlanta, Ga.	3400 Malone Drive, Chamblee, Ga.	30005	404	457-6341
Baltimore, Md.	8635 Loch Raven Boulevard	21204	301	668-8800
Boston, Mass.	Waltham Industrial Center	02154	617	894-6100
Buffalo, N. Y.	2051 Elmwood Avenue	14207	716	875-9600
Charlotte, N. C.	Mail Add.: P.O. Box 128, Atando Station	28206	704	377-1557
	Whse.: 321 West 32nd Street			
Chicago, Ill.	4501-4531 W. Cortland Street	60639	312	772-0300
Cincinnati, Ohio	10555 Taconic Terrace, Woodlawn Industrial Park	45215	513	771-1310
Cleveland, Ohio	Mail Add.: P.O. Box 9586	44139	216	248-9400
	Whse.: 31400 Aurora Road, Solon, Ohio (Gr. Cleve.)			
Dallas, Texas	Mail Add.: P.O. Box 471, Arlington, Texas	76011	214	943-7307
	Whse.: 1101 Ave. H East, Great Southwest, Texas	76010		
Denver, Colo.	6301 Dexter Street, Commerce City, Colo.	80022	303	288-2655
Detroit-Toledo	4920 E. Nevada Avenue, Detroit, Mich.	48234	313	366-4400
	Greater Toledo		419	382-5678
Fort Worth, Texas	Mail Add.: P.O. Box 471, Arlington, Texas	76011	817	274-1343
	Whse.: 1101 Ave. H East, Great Southwest, Texas	76010		
Grand Rapids, Mich.	4000 Eastern Avenue, S.E.	49508	616	245-1185
Houston, Texas	Mail Add.: P.O. Box 2128	77001	713	921-7113
	Whse.: 6416 Navigation Boulevard			
Indianapolis, Ind.	105 South Keystone Avenue	46201	317	638-4501
Los Angeles, Calif.	6033 E. Bandini Boulevard	90022	213	723-4821
Miami, Florida	2891 N.W. 75th Street, P.O. Box 545	33147	305	691-8940
Milwaukee, Wis.	Mail Add.: P.O. Box 6007, Station 'F'	53209	414	461-2900
	Whse.: 4200 West Douglass Avenue			
New Haven, Conn.	285 State Street, North Haven	06473	203	288-2581
New Jersey	Mail Add.: P.O. Box 556, West Caldwell, N. J.	07007	201	226-9300
	Whse.: 25 Greenbrook Road, Fairfield, N. J.			
New York	80 Newtown Road, Plainview, L. I., N. Y.	11803	516	694-7020
			212	461-6500
Philadelphia, Pa.	408 South Oak Avenue, Primos, Delaware County, Pa.	19019	215	748-6600
			215	259-9500
Pittsburgh, Pa.	Mail Add.: P.O. Box 4514	15205	412	922-3602
	Whse.: Campbell's Run Road near Rte 60,			
	Robinson Twp. (Greater Pittsburgh) Pa.			
Portland, Oregon	2330 N.W. Raleigh Street	97210	503	222-1768
Providence, R. I.	Mail Add.: P.O. Box 2096	02905	401	781-4141
	Whse.: 141 Carolina Avenue			
Salt Lake City, Utah	753 West Eighth Street, South	84104	801	364-4385
San Francisco, Calif.	1255 22nd Street	94107	415	282-8011
Seattle, Wash.	5964 Maynard Avenue, S.	98108	206	722-8929
Springfield, Mass.	53 Second Ave., Chicopee Falls, Mass.	01020	413	592-7701
St. Louis, Mo.	8610 Page Boulevard	63114	314	429-4400
Syracuse, N. Y.	Mail Add.: P.O. Box 662, East Syracuse, N. Y.	13057	315	437-8391
	Whse.: Boss & Thompson Roads, East Syracuse, N. Y.			
Tampa, Florida	2402 35th Street, P.O. Box 1527	33601	813	248-5039
Tulsa, Okla.	2420 W. Skelly Drive	74107	918	446-5511
Twin Cities	2911 Como Avenue, S.E., Minneapolis, Minn.	55414	612	331-6320

CRUCIBLE STEEL COMPANY OF AMERICA

Four Gateway, P.O. Box 88, Pittsburgh, Pa. 15230

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